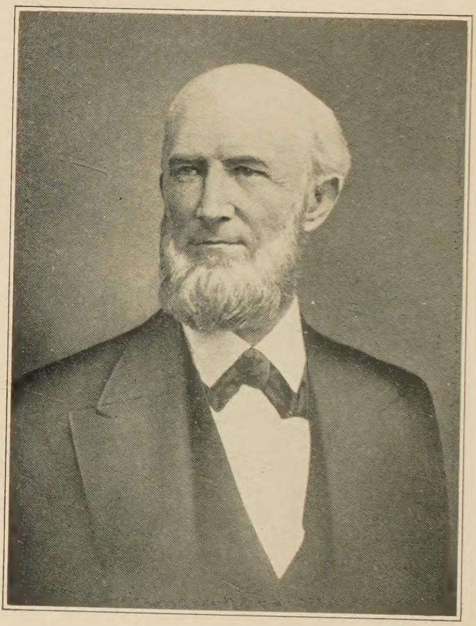
GINN
AND
COM-
PANY

ENGINEERING SERIES

EDITED BY

ANDREY A. POTTER, ENG.D.

DEAN OF THE SCHOOLS OF ENGINEERING, AND
DIRECTOR ENGINEERING EXPERIMENT
STATION, PURDUE UNIVERSITY



JAMES B. EADS

THE ENGINEER

HIS WORK AND HIS EDUCATION

BY

ROBERT LEMUEL SACKETT, C. E.

DEAN OF ENGINEERING, THE PENNSYLVANIA STATE COLLEGE

GINN AND COMPANY

BOSTON · NEW YORK · CHICAGO · LONDON
ATLANTA · DALLAS · COLUMBUS · SAN FRANCISCO

PRINTED IN THE UNITED STATES OF AMERICA

328.8

The Athenæum Press
GINN AND COMPANY · PRO-
PRIETORS · BOSTON · U.S.A.

PREFACE

This book is dedicated to those who are considering engineering as a life work. Over fifty thousand students are now studying engineering in colleges and universities of the United States, and about fifteen thousand are each year entering such training courses.

They should know something about engineering as a profession and about the college course which helps them to prepare for it. The recent investigation of engineering education carried out with the support of the Carnegie Corporation through the initiative of the Society for the Promotion of Engineering Education has disclosed that too frequently the applicant for an engineering course has an erroneous or a very vague notion of the nature of engineering practice.

This investigation showed that something should be done to guide the boy to make a wise decision in choosing a life work. A number of valuable pamphlets have been prepared by various institutions for the use of high-school boys, their parents, teachers, principals, and superintendents. The writer edited one of these and found a large demand for it. Other institutions have had similar experience. There are a number of books on this subject, but the investigation referred to above has made available a large amount

of new information bearing on the subject "Who should study Engineering." The usefulness of a short guide is obvious.

Acknowledgment is due to the Society for the Promotion of Engineering Education, and to the director, W. E. Wickenden, for permission to use the results of its survey; to members of the faculty of the Engineering School of Pennsylvania State College, who devoted time to the preparation of a pamphlet of merit; to Dr. E. D. Ries of the School of Chemistry and Physics, who wrote the section on Chemical Engineering; to Dean A. A. Potter of Purdue University, and to others who criticized portions of the manuscript.

R. L. SACKETT

CONTENTS

CHAPTER		PAGE
I.	THE SELECTION OF A VOCATION	1
II.	ENGINEERING AS A LIFE WORK	11
III.	A BRIEF HISTORY OF ENGINEERING	40
IV.	THE COLLEGE COURSE IN ENGINEERING	60
V.	ARCHITECTURE AND ARCHITECTURAL ENGINEERING	75
VI.	CIVIL ENGINEERING	82
VII.	ELECTRICAL ENGINEERING	96
VIII.	MECHANICAL ENGINEERING	110
IX.	INDUSTRIAL ENGINEERING	120
X.	CHEMICAL ENGINEERING	126
XI.	MINING AND METALLURGICAL ENGINEERING	130
XII.	OTHER ENGINEERING COURSES	134
XIII.	TEACHING AND RESEARCH	139
XIV.	THE ÆSTHETIC, CULTURAL, AND ROMANTIC IN ENGINEERING	146

APPENDIX. SHORT BIOGRAPHIES OF ENGINEERS WHO HAVE MADE HISTORY

LEONARDO DA VINCI	157
JAMES WATT	159
JOHN ERICSSON	162
JAMES B. EADS	166
JOHN A. ROEBLING AND HIS SON, WASHINGTON ROEBLING	169
GEORGE WESTINGHOUSE	172
SAMUEL REA	175
GEORGE W. GOETHALS	178
CHARLES P. STEINMETZ	182
HERBERT C. HOOVER	185
JOHN H. HAMMOND	189
CHARLES M. SCHWAB	192

INDEX 195

THE ENGINEER: HIS WORK AND HIS EDUCATION

CHAPTER I

THE SELECTION OF A VOCATION

The selection of a vocation is made by the majority of young people while they are still in high school and before they have had much experience in or observation of modern business or industrial occupations.

If they seek employment, there is a broad field from which to choose, such as mercantile, shop, and factory occupations, the building trades, salesmanship, and many others. Each field is divided into several parts, and seeks young men who are quick and eager to learn, ambitious, honest, and loyal. Each offers an opportunity for the right kind of ability and personality. The numerous captains of business and industry prove that where there are skill and will, there is a way up.

If the high-school graduate decides to go to college, he is faced here too with the necessity of choosing from a wide variety of courses or curricula, each with its special requirements and purposes. If he looks ahead, he finds a confusing number of vocations and special

subdivisions of each, which make his choice still more difficult. It is therefore very important that information should be available which will help the prospective engineer to learn more about the nature and essential requirements of the subjects which the student pursues, the work of the beginner in engineering, and the branches to which he may seek promotion.

In the investigation conducted by the Society for the Promotion of Engineering Education, about four thousand students admitted to curricula in thirty-two engineering institutions were asked the basis of their decision to go to college.

Approximately one half of the students indicated that advice had been a factor in their decision to go to college. On the other hand such reasons as the desire to earn a good living, the desire for a higher education or for general self-improvement were given in a considerably larger percentage of cases. About four tenths of the students indicated that the desire to become an engineer had been an important factor in their decision.

Advice was a still less important factor in students' decisions to study engineering. Only 24 per cent indicated that they had based this decision upon the counsel of others, and only 5 per cent indicated that they had profited by the advice of teachers. The outstanding reason for the choice of engineering appears to have been its definite appeal; second to that are such reasons as the belief that an engineering training promised to provide a good living.

In the selection of a particular course of study it is apparent that advice played very little part, since

only 10 per cent of the students indicated that advice of parents, teachers, or others had influenced them.

It is also important to note that a majority of students entering engineering courses form their decisions to go to college and to study engineering at an

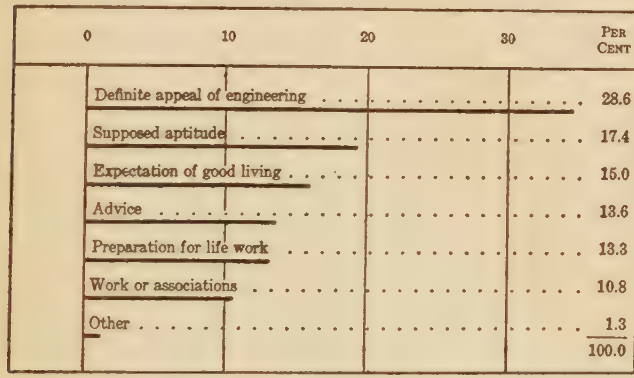


Fig. 1. Relative weight of different factors in students' decision to study engineering

early date. More than three fourths reached a decision to study engineering before graduating from high school, and slightly more than half formed the decision before entering the last year of high school.

As a check on the validity of the basis of the students' decision they were asked to write a short statement of their conception of the field of engineering, of the work of the engineer, and of their understanding of the nature of the particular field of engineering which they had elected to enter. These papers were rated by members of the faculties and gave results indicated in Fig. 2 on page 5.

It appears that well over half the students have little or no conception or a poor conception of these matters, though they have formed a most important decision on the basis of that conception.

STUDENTS' CONCEPTION OF ENGINEERING AS EVIDENCED EARLY IN FRESHMAN YEAR

Little or none	18.7%	
Poor	37.9	
		56.6%
Good	30.5%	
Excellent	12.9	
		43.4%

In connection with this very significant statement consider that these students have on the average ranked well in high school. Of the same students 18 per cent were honor students; 42.6 per cent were in the upper third; 36.8 per cent were in the middle third; and only 2.6 per cent were in the lower third of their high-school classes.

Also note that of the freshman class of 4079 mentioned above, some 40 per cent would probably not return to college after the first year. This fact was determined by data obtained from thirty-eight representative institutions which had investigated the records of their students. There are a number of causes for this shrinkage, but it seems safe to conclude that ignorance of the preparation, training, and experience of engineers is a factor of some importance.

It is the purpose of this book to point out the mental qualities which are desirable in the engineer-

ing student; the aptitudes which are helpful in making a choice of a course; and the nature of the studies, their purpose, and the various kinds of work which the engineer does while he is gaining experience.

The author realizes fully that the student must study himself, his likes and dislikes, his aptitudes and

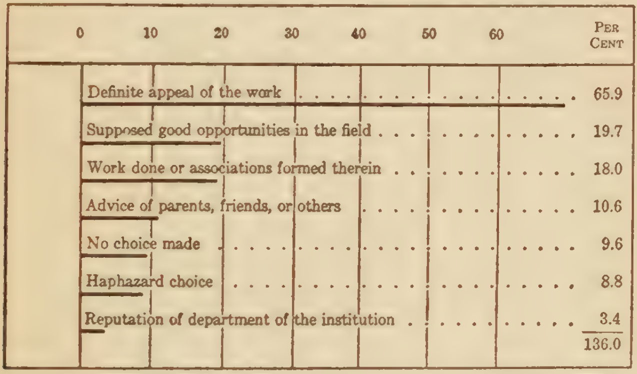


FIG. 2. Basis of students' choice of a particular course in engineering

Since students were permitted to indicate more than one basis of choice, the total is more than 100 per cent

personality, and then make his choice. No one can feel of his bumps, look at his life line or the shape of his fingers, and select for him the work which he should follow. The psychologist has not yet progressed to the point where tests will do more than suggest in a broad way the fitness of the youth for specific vocations or professions. The physician, the lawyer, and the engineer can all utilize many of the same mental qualifications. Each may have mathematical ability,

but the engineer *must* possess it; each may be scientific in his tastes, but the physician and the engineer should be distinctly so; each should be judicious, analytical, honest, courageous. An exceptional personality goes a long way in any case, and may be the dominant factor in the rise of many men to executive positions of great importance.

Many prominent engineers are mentioned in Chapter III, short biographies of some are given in the Appendix, for the purpose of impressing on the young student the fact that men have risen and are rising from very humble beginnings to places of great responsibility in the engineering world. Something of the romance of engineering and of the service of engineers to civilization appears through the sketches of these men and their works. When time has cleared away the mists that enshroud the present, historians will agree that the engineer has been among the great benefactors of the human race.

What is the purpose of engineering education? Some are born engineers, and some are engineers by virtue of training and experience. Statistics have shown that a high degree of intelligence is necessary if positions of importance are to be obtained; but our methods of determining relative intelligence are not perfect and never will be, because intelligence is too elusive and too complex for precise measurement.

Engineering education does not *make* engineers, but it offers to those of good intellectual endowment a

preparation in fundamental subjects of study, a survey of the fields of engineering, and mental discipline in the processes of analysis which the engineer employs.

Experience — long experience — is a necessity before one becomes an engineer. Engineering education is a continuous process, and experience is the schoolroom. College days are limited to four, five, or six years in the case of those who pursue the usual undergraduate curriculum and one or two years of graduate study. This is but the initiation, or the probationary period. Only the fundamental subjects are taught; the student is immature, and has had little if any contact with engineering practice.

Statistics show that over 50 per cent of our engineering graduates are gradually promoted to supervisory or executive positions. Some become owners or partners in an engineering or industrial business, but the average engineering curriculum offers little training in the essential elements of good administration. This ability is not reducible at present to academic terms and is largely a matter of personality.

On the other hand, a large amount of data collected in the course of three investigations shows that the student who fails to complete his undergraduate engineering course has little chance of becoming a success. Such qualities as perseverance, will power, and personality undoubtedly spur many students of moderate mental ability — as compared with their fellows — to graduation and to success in executive positions. It

would be a mistake to conclude that executives as a class were not able students, for they are usually men of exceptionally keen minds. *But* something more is necessary, and this is personality and character.

The purposes in engineering education are broader than to train a young man merely for civil engineering or for any other engineering profession: they are to train him for citizenship, for service, and for living. To this end there are courses in economics, government, and psychology, and lectures by visiting engineers who speak on the broader aspects of engineering. Students are encouraged to join the student branches of the national engineering societies, where they make contact with the leaders of the profession and learn the ethics of it.

The code of the American Society of Civil Engineers is as follows:

American Society of Civil Engineers
Code of Ethics

It shall be considered unprofessional and inconsistent with honorable and dignified bearing for any member of the American Society of Civil Engineers:

To act for his clients in professional matters otherwise than as a faithful agent or trustee, or to accept any remuneration other than his stated charges for services rendered his clients.

To attempt to injure falsely or maliciously, directly or indirectly, the professional reputation, prospects, or business of another engineer.

To attempt to supplant another engineer after definite steps have been taken toward his employment.

To compete with another engineer for employment on the basis of professional charges, by reducing his usual charges and in this manner attempting to underbid after being informed of the charges named by another.

To review the work of another engineer for the same client, except with the knowledge or consent of such engineer, or unless the connection of such engineer with the work has been terminated.

To advertise in self-laudatory language, or in any other manner derogatory to the dignity of the profession.

The young engineer needs a positive code of ethics as well as the negative one given above. He should strive to be not only the best engineer which he is capable of being, but also a useful member of society, — one who will take his place in public affairs. To this end his education, not only while he is in college but after he leaves college as well, his self-education, should include more than just that which concerns his job. His professional services will not reach their full fruition in many instances unless the engineer is prepared to be, and able and willing to be, an active citizen as well as an engineer.

The objective of an engineering education is to provide society with men who have had that general education so aptly formulated by the Greek philosopher Plato when he said that "good education is that which gives to the body and to the soul all the perfections of which they are

capable," and, in addition, have been trained in a knowledge and understanding of the exact sciences through the applications of which they are enabled to promote the physical well-being of the community. By their habits of exact thinking and constructive outlook, engineers are particularly able to serve as leaders in public and private affairs, because, guided by truths already discovered, they look forward to find safe and sound footings for new structures, rather than look backward at the cold stones of precedent. This pioneer spirit, well grounded and intelligently directed, is the great asset of the engineer.[1]

BIBLIOGRAPHY

Bulletins of the Investigation of Engineering Education by the Society for the Promotion of Engineering Education. The Lancaster Press, Lancaster, Pa.

Journal of Engineering Education. The Lancaster Press, Lancaster, Pa.

[1] Magnus W. Alexander, "The Objective of Engineering Education," Proceedings of the American Society of Civil Engineers, Vol. LXXXVI (1923), p. 1256.

CHAPTER II

ENGINEERING AS A LIFE WORK

In the Middle Ages the majority of boys were indentured by their parents as apprentices to master carpenters, millwrights, iron workers, goldsmiths, or other tradesmen, whom they served in this capacity for a period of four or more years. After this they became "journeymen"; that is, they were certified as skilled artisans and practiced their trade, many of them becoming masters and employing a few workers under them. Only a very small number studied theology; and a still smaller number read law, or entered the office of a practicing physician or the shop of an apothecary.

The organization of industry gradually changed from the condition in the Middle Ages, when the household arts provided for the majority of the needs of the family. New trades were added, such as those of the goldsmith and silversmith, the weaver, the wheelwright, and the millwright. Although a number of apprentices and journeymen might be employed by a master, the relation of master and servant was comparatively intimate and simple.

It was not until the steam engine, the power loom, the machine tool, the power hammer, the steam loco-

motive, and steel came into use that the organization of industry began to change radically. Invention, improved transportation, and communication brought more distant markets, created new demands, and led to larger numbers of employees in one organization. The division of labor, automatic machinery, piece work, and increased production lowered costs; they created capital and required supervision. These changes demanded design, economy, planning, engineering, financing, management.

Today a considerable percentage of high-school students plan to enter a college or university with the intention of preparing for a life work in theology, law, medicine, business, industry, education, agriculture, pure science, or engineering. Each of these fields is divided into a number of specialties which still further complicate the choice.

Furthermore, the increase in the size of cities, together with the provision of light, water, milk, food, and clothing by organized business, leaves few "chores" for the father to do and fewer tasks for the boy. The latter has small experience on which to base a choice, and fewer opportunities to obtain contacts with different industries or to gain manual skill, which is useful, though not as significant as it was before the industrial age in which we now live.

Skilled artisans are still needed in the building trades, in wood and metal manufacturing, in machine and engine building. Draftsmen are required in all kinds of

metal-working industries, where old designs are being remodeled or new designs added. In building contracting and bridge construction, foremen are in constant demand, and there is opportunity for promotion for those who show skill and have the right kind of personality. These vocations should not be overlooked by the high-school boy as he surveys life and seeks for his place.

For those who are considering some phase of engineering, experience of almost any kind in the summer and during odd hours is desirable. Selling newspapers, magazines, aluminum ware, brushes, — anything, — gives the boy a knowledge of what earning money means and requires. It develops also a knowledge of people and how to approach them. It requires pleasing manners and a good disposition. Experience on surveying corps, on highway construction, in the shop, in industry, is valuable for the information gained and for the human contact which stabilizes the individual and gives him a sense of economic independence.

The investigation of engineering education recently made shows that employment before entering college is rather general among engineering students. The evidence gathered from over four thousand freshmen in thirty-two engineering schools and colleges showed that 90 per cent of them had worked during the preceding year, and that their average earnings were $417 and their average savings $219, — enough in many colleges to pay for their tuition and books for the first

year. This thrift is to be commended. It shows also that boys can and do go to college from families of modest income, where work is looked upon as both natural and dignified. Many engineering schools require the student to work part time during his course or during his summers as a preparation for graduation. He must obtain the approval of his employers, showing that he is diligent and punctual, is improving in skill, and is able to work with others.

To the young man in high school or in preparatory school one of the questions which he must confront and which must be answered in the majority of cases is "What am I going to do?" "Shall I become a lawyer, a doctor, an engineer?" or "For what am I best fitted?"

"Which pays best?" In many cases the boy and even his parents assume that he can do anything, and one thing as well as another; hence the main question is "What pays best?" The fact is that environment or the work which his father, brother, or friends do, his early experiences, his contacts with men and machines, or even his play may influence his tastes and his aptitudes and make it highly desirable that he should choose one life work rather than another.

Bishop Charles Lewis Slattery, of Boston, said in the *Harvard Alumni Bulletin* for January 7, 1926:

In the first place, you ought not to choose any vocation because you think that you can earn your living by it. Again and again, I come in contact with men who tell me

that they have started out in life merely with the idea of getting a living. They see people living on a certain scale, and they would like to live just about as these people are living; they wish to get married, for instance, and they wish to have a home; so they look about for something which will give them enough income to support a family with what they believe will be sufficient comfort.

That is the wrong way to start. You want a living, of course, and you will get a living if you have the right vocation. But you court failure in life if you think first of getting a living. You must choose a life-work in and for itself; whether it will give you a large or a small income is immaterial. Your first task is to find something which will so arouse your enthusiasm that you feel that you could not do anything else and be really happy.

It is quite human to ask whether a certain field offers profitable employment. Few would have the courage deliberately to select a profession for which there was no demand. In general there is a place for the earnest, capable graduate in almost any field of science and its applications. Data will be presented later which show the earnings of engineering graduates.

Each student should capitalize his talent by training it at the same time that he is obtaining a broad education. But many students have not yet discovered their talent. How can they find their bent, their ability, the kind of work which they can probably do to the best advantage and with the greatest satisfaction?

Aptitude. This is a natural or acquired ability to do certain things better than certain very different things.

Not all students are excellent in mathematics, and not all are skillful in using tools. By the time high school is reached some have shown a keener interest in one subject than in another and have attained a greater degree of skill in learning the subject which they prefer. Certain forces have been at work, of which we may be unconscious and which determine the field of our greatest aptitude. Other things being equal, the field of our greatest interest and aptitude is the desirable one to pursue unless handicaps of health or other factors compel one to struggle to develop new aptitudes and new skill. To succeed in a radically different occupation requires time, sacrifice, and unusual will power. On the whole, the boy should pursue, if possible, that for which he seems best fitted. There he should succeed best, be happiest, and be of the greatest service. The question is not, then, "What pays best?" but "For what am I best suited?"

Determining aptitude. It is easy for some boys to decide on their life work. The answer comes naturally and without conscious effort; the decision is made when the time comes to make it. The father is an engineer; the son has absorbed much of the nature of the problems dealt with, senses in an indefinable way the importance of mathematics, of experience, of careful judgment, and decides to be an engineer. In another case, however, the father may not recommend his work to his son. The latter has had very little experience with any kind of job and does all his lessons

in merely passable fashion. To determine what life work to select is a difficult and an important problem to which the father, the teachers, and the boy should apply themselves.

Various kinds of aptitude. Every normal boy is interested in engines, automobiles, radio, aviation. He is curious to know how a motor works. This may mean much or little. Many boys, and men too, upon seeing a wireless set can make a similar one. This may show manual skill and a capacity to imitate, but it does not signify a particular aptitude for radio engineering. Some boys enjoy manual training in school, become skilled in using tools, are "handy"; but this by itself does not indicate an aptitude for engineering. It is a useful trait, but not a criterion.

The power of the locomotive, as it thunders by at a speed of sixty or seventy miles an hour, thrills the average boy. The speed of the airplane has a strong attraction for him; but something more than curiosity, power to imitate, and thrill is necessary in the make-up of the engineer. We shall speak of the romance of engineering later on; but just now we must face the cold, hard facts.

In the first place, no set of intelligence and aptitude tests has yet been developed on which teachers, parents, or students can depend to determine for which of a thousand vocations a boy is best adapted. We know from experience that only those who have ranked in the top third in their high-school grades stand a good

chance of succeeding in an engineering course. There are exceptions, but they are comparatively few in proportion to the total. At the same time, the special abilities which so largely influence success in the majority of vocations have not yet been satisfactorily analyzed, much less measured. The intangible factors of interest, will power, social adaptability, leadership, and personality are still less subject to exact determination, although their combined influence upon vocational success is very great. One's general ability may fit him equally for success in a dozen different vocations, and in this case the ultimate choice should depend upon practical considerations, natural interests, and various traits of personality.[1]

Considerable progress in the study of aptitude has been made since the foregoing statement was written; but the conclusion remains, and the general effect of recent tests is to eliminate rather than to select. Undoubtedly, in time, advance will be made in measuring occupational fitness or intelligence; and when that time comes, such measurement will be of the greatest value in vocational guidance.

Tests to apply. Do you really like mathematics? Are you good in science, so far as you have studied it? Do you enjoy drawing?

Mathematics is the most valuable tool which the engineer uses. He employs it in one form or another

[1] Lewis M. Terman (Stanford University, California), The Intelligence of School Children. 1919.

in all his designs, and life depends on the correctness of his figures. He plans a bridge, which means not merely that a few lines are drawn but that careful calculations, some simple and some complex, must be made, and made accurately. Bridges cost money, and the expense must be kept low. At the same time, the bridge must be safe, and its safety depends on the accuracy of the computations by which the sizes and shapes of columns and girders are determined.

Not only is mathematics important as a tool but it is a valuable form of mental discipline. It teaches careful reasoning and painstaking accuracy. Therefore the usual engineering course in college contains a large amount of mathematics and mathematical discipline. Some things are done by "cutting and trying"; but a mathematical mind is a logical mind, and proceeds by argument from one step to the next. Some students try to memorize geometry, trigonometry, and the succeeding mathematics. A good memory is a great asset to anyone, and certain facts and definitions must be remembered; but the essential steps in mathematics depend upon a clear perception of the reasoning which connects the premise with the first step and that with the next step.

Do you like science, especially physics? Science is the orderly arrangement of facts from which natural laws are induced. In physics the student learns the laws of gravitation — of falling bodies — and the laws under which all kinds of motion take place. What is

force and how is it measured? The laws governing forces lie at the very root of many branches of engineering. Roof trusses, bridges, arches, boilers, engines, airplanes, ships, motors, electrical-transmission lines, — all depend for their safe and economical design and construction on the laws of force, — on physical laws, or natural laws (that is, the laws of nature). Therefore it is important that the boy who intends to take an engineering course should like physics and make good grades in it.

Chemistry is the foundation of the study of metals and their alloys, or metallurgy, and of the composition of fire brick, tile, and other clay and shale products. It is necessary also in the study of petroleum, gas, and coal. The geologist needs chemistry. The chemical industries, such as those which manufacture dyes, paints, drugs, and other chemicals, depend on it as a foundation. The boy who intends to enter any of these fields should enjoy chemical theory and the laboratory.

In a previous paragraph it was stated that skill with tools does not signify ability to succeed in a college engineering course. This needs to be discussed further in order that it may be clearly understood.

The creative instinct. The engineer is a builder, a creator, and should have the creative instinct. If you like to "make things" it is of significance. But many boys use tools with more or less effect. Some use them indifferently and with no set aim or purpose. Others *plan* to make a water wheel, draw it, *measure* the parts

carefully, and *finish* the job. This is indicative of the creative instinct, but it may be applied on the farm or in a variety of other occupations. The engineer should have it in a pronounced degree, but by itself it does not mark one as an embryo engineer.

Curiosity. We have said that most boys are curious to know how to run an automobile, a radio set, a motor, or any other unfamiliar machine. Many, however, have no desire to know more than *how* it works. The engineer desires to know *how* apparatus works, and he should be deft or skillful in handling machinery. But even more important is the desire to know *why* it works. In other words, the engineer must be keenly interested in the *principles* on which instruments, apparatus, and engines operate.

It is therefore important that you ask yourself and answer honestly the question "Do I really want to know why?" If you are satisfied, in taking a clock to pieces, to see of what it is made, that signifies very little. Everybody does it. But if you can put it together, make it run, and find out *why* it works, that is indicative that you possess one quality which the engineer should have. It has been said that there will always be a place for the man who knows *how* to run machinery, but that the man who knows *why* it runs will be his boss. Think it over.

Imagination. Another desirable quality is that which is called imagination. Read Victor Hugo's description of the battle of Waterloo in "Les Misérables." Can

you picture the movements of the troops of Napoleon and Wellington and *see* the succeeding formations as the combatants approach and engage in battle? Do you naturally picture in your mind the battlefield and the actions taking place?

This is an important quality; for the engineer must be able to imagine the finished building, machine, engine, or power plant from the drawings. His mind is the telescope through which he looks ahead and sees the steps in the design, construction, and operation of a machine or of an assembly of such apparatus as constitutes a power plant. A noted engineer took the contract for furnishing air-brake apparatus for the Manhattan-Brooklyn subway system before the apparatus had been designed. The brake equipment was then designed, built, and put into operation. It worked successfully, although it embodied new ideas. The engineer knew the fundamental principles and *saw* in his mind the details of design, the difficulties of manufacture, and the usual causes of failure in operation. His imagination was trained to see ahead; it was a factor in his success.

If you like mathematics, physics, and chemistry, if you enjoy planning and carefully making things, if you have a natural desire to know *why*, — that is, to know the principles on which an apparatus operates, — if you have imagination, then you have the qualities of a good engineer, and their possession is a strong indication of aptitude for engineering. To conclude, then,

the engineer must have imagination; he must also be accurate in thought, have capacity for sound judgment, be ingenious, have a scientific curiosity, a desire to create, and in addition he should possess the highest integrity of character.

Engineering functions. The field of engineering is divided into several branches, among which are architectural, civil, and electrical engineering. In addition, each of these is characterized by a variety of functions which may be classed as *design*, *manufacturing*, *construction*, *sales*, *operation*, *administration*, and *research*. It is desirable that they be defined so that the student may consider his aptitude and ability in each. When he enters engineering employment, he will be assigned to one of these functional divisions, or, in the cadet courses provided for the early training of graduates, he may have experience in each of several functional divisions of the plant.

1. *Design.* This includes the calculation of dimensions; the selection of materials; the specification of parts and of completed structures; the preparation of practical, *economic* plans for machinery, buildings, bridges, power plants, railways. It is creative work, — *not drafting.*

2. *Manufacture.* This is the execution of the plans of the designer. It includes the determination of processes of manufacture and the selection and operation of tools. Factory planning and works management are also important features.

3. *Construction.* Construction of power plants, transmission lines, railroads, bridges, water, sewerage, and lighting systems, and public works, as well as the installation of machinery and apparatus, are included under this function.

4. *Sales.* This includes selling machinery or power service, giving technical advice to the purchaser, and helping him to solve his engineering problems.

5. *Operation and maintenance.* Operation and maintenance of power plants, manufacturing plants, railroads, transmission systems, and water works are important supervisory functions. Service work and plant repairs are also included.

6. *Administrative and executive functions.* These include executive responsibilities in directing public utilities, technical industries, municipalities, and engineering corporations.

7. *Research.* In this field, studies are made in laboratories to find new materials, to develop better ways of making things, or to find the laws which will explain physical, chemical, or other phenomena. The purpose is first to find out *why* and then to develop something new, or to find a cheaper or better way of making a device, product, or material. (See Chapter XIII.)

Personal qualifications. We assume that the high-school student who is considering his fitness for engineering will possess the fundamental requirements for success in any honorable calling, such as excellent

moral standards, high ideals, self-discipline, industry, initiative, and judgment.

The other qualities may be divided into three groups:

1. *Technical*
   - Outstanding ability in mathematics and the physical sciences
   - An analytical mind, capable of critically studying technical problems and of arriving at their correct solution
   - Interest in abstract and difficult problems
   - An inquisitive mind which seeks reasons for all things
   - Enjoyment in working with inanimate things
   - Originality of thought and action
   - A thorough knowledge of the theoretical side of engineering

2. *Physical*
   - Good health
   - Endurance
   - Neatness of appearance and dress
   - Freedom from physical deformities or handicaps
   - Physical activity

3. *Social*
   - Ability to make friends quickly
   - Ability to make favorable first impressions
   - Desire for companionship
   - Conversational ability
   - Breadth of interests
   - Elements of leadership

High technical qualifications are of great importance to the design and research types of engineers. Good physical qualities are important to the manufacturing, the construction, and the operating engineer. Social qualities are helpful to all branches of the profession.

DOES AN ENGINEERING EDUCATION PAY?

The cost of a college year in engineering varies with the tuition charged and the habits of the student. From $600 to $1000 per year is probably representative. If we take $800 per year as an average, the capital cost is $3200, plus interest at 6 per cent for $3\frac{1}{2}$, $2\frac{1}{2}$, $1\frac{1}{2}$, and $\frac{1}{2}$ years. Compounded annually this amounts to a total of $3600. In addition there is the loss of earnings during the four school years, amounting to an estimated $6000, less cost of living and with interest on the savings; say, a net loss of $4000. The total investment is therefore roughly $7600, less earnings in the summer (which we may omit from consideration).

Will this sum be recovered? If so, how long a period is necessary before paying off the debt, and how will the college graduate compare with the high-school graduate who enters industry or engineering after each has worked five, ten, fifteen, or twenty years? The answer is that it depends on the boy.

The investigation by the Society for the Promotion of Engineering Education previously referred to, and others conducted by different engineering colleges, show

that the college graduate, like his non-college competitor, varies in income according to his ability, personality, ambition, and willingness to work and to take responsibility. Chance plays a small part in the result.

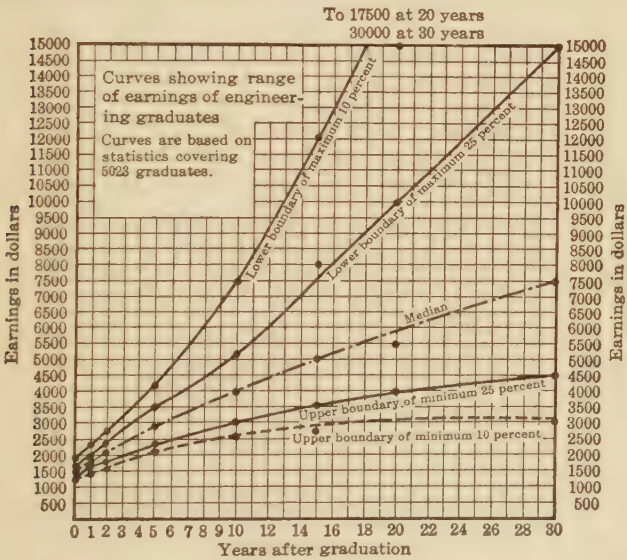


FIG. 3. Earnings of engineering graduates

Earnings of graduates. Information from over five thousand graduates of more than forty institutions in the United States and Canada was plotted, and from it were constructed the curves shown in Fig. 3, which show the relation between annual earnings and the number of years since leaving college.

The earnings of recent graduates seem to increase steadily and satisfactorily, their progress being approximately

three hundred dollars per year in annual salary, as shown by the following table:

Median Earnings of Recent Graduates

	Per Month	Per Year
Immediately after graduation	$123	$1476
Six months after graduation	133	1596
Twelve months after graduation	150	1800
Twenty-four months after graduation	175	2100

The progress of older graduates seems fair, though the rate of increase of the early years is not maintained.

There do not seem to be extreme variations between earnings of graduates of different institutions, certainly none greater than would be expected owing to varying economic conditions of different parts of the country. Maximum and minimum median salaries of graduates at the beginning of 1925 reported by the various institutions are:

Class of 1924	minimum	$110 per month
	maximum	175 per month
Class of 1923	minimum	130 per month
	maximum	219 per month
Class of 1922	minimum	140 per month
	maximum	250 per month

It has been found that after about five years personal qualities begin to assert themselves and to influence the salary received and also the position occupied.

Types of positions occupied. The figure which follows shows the types of positions, or kinds of work, of engineering graduates. Of the recent graduates 59.6 per cent are in technical engineering, 11.5 per cent are in research and teaching, 16.2 per cent in sales and administrative work, and 12.7 per cent in clerical, manual,

or miscellaneous work. Of the older graduates 22.5 per cent are in strictly technical work; 10.1 per cent are in research and teaching (note the slight change from recent graduates); 63.9 per cent are in ownership, executive, and administrative work, including sales; and 3.5 per cent are in clerical and miscellaneous work.

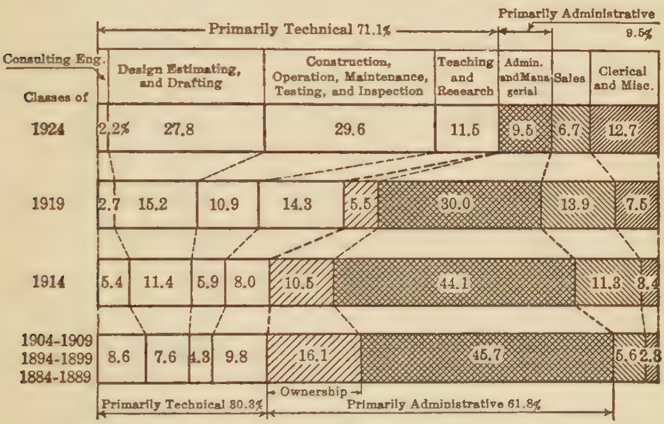


FIG. 4. Progressive trend of engineering graduates to managerial duties

These figures show a healthy progression through technical work toward management, and indicate also that engineering courses fit graduates to a satisfactory degree for the responsibilities of the direction of American industry. Fig. 4 shows this strikingly.

Several thousand graduates have testified to the value of their engineering course, and of five thousand about 98 per cent "feel that they made no mistake in taking an engineering course."

It is a matter of great significance that a large percentage of those graduating from a given course have remained in the work related to the course. The following tables show the relationship of fields of work of graduates to courses pursued in college. Fig. 5 is a composite of the data of the tables. In both tables and figure "same field" includes those subdivisions which are usually recognized as a part of the major field itself. Sanitary engineering and hydraulic engineering, for example, are taken as parts of civil engineering. "Closely associated fields" are those closely related to the major fields, such, for example, as marine engineering (related to mechanical engineering). "Unassociated engineering field" may be illustrated by the case of a graduate of civil engineering who is employed in electrical-engineering work. It will be noted that 60 per cent of all graduates who supplied information are in the same lines of work as their college courses, approximately one quarter are in "closely associated" or "unassociated" lines of engineering, and the remaining 15 per cent have left engineering.

These figures seem to disprove the statement so often heard that large proportions of graduates leave engineering for other activities. A comparison of the tabulations of recent and older graduates shows that there is some drift away from fields directly related to college courses, but not more than would seem to be entirely healthy. More civil-engineering graduates remain in lines of work directly related to their college course

Relationship of Fields of Work of Recent Graduates to College Courses

Courses Graduated from	Present Fields of Work								Totals
	Engineering						Non-engineering		
	Same Field		Closely Associated Field		Unassociated Field				
	Number	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*	
Chemical engineering	210	50.0	47	11.2	70	16.6	93	22.2	420
Civil engineering	609	83.3	18	2.5	59	8.1	45	6.1	731
Electrical engineering	672	75.3	44	5.0	85	9.5	91	10.2	892
Mechanical engineering . . .	515	52.9	89	9.1	238	24.5	131	13.5	973
Mining engineering	96	55.5	33	19.1	23	13.3	21	12.1	173
Totals	2102	66.0	231	7.2	475	14.9	381	11.9	3189

Relationship of Fields of Work of Older Graduates to College Courses

Courses Graduated from	Present Fields of Work								Totals
	Engineering						Non-engineering		
	Same Field		Closely Associated Field		Unassociated Field				
	Number	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*	
Chemical engineering	69	49.3	16	11.4	33	23.6	22	15.7	140
Civil engineering	494	66.0	39	5.2	90	12.0	126	16.8	749
Electrical engineering	309	50.0	41	6.7	133	21.6	134	21.7	617
Mechanical engineering . . .	292	51.4	63	11.1	104	18.3	109	19.2	568
Mining engineering	44	42.3	8	7.7	28	26.9	24	23.1	104
Totals	1208	55.5	167	7.7	388	17.8	415	19.0	2178

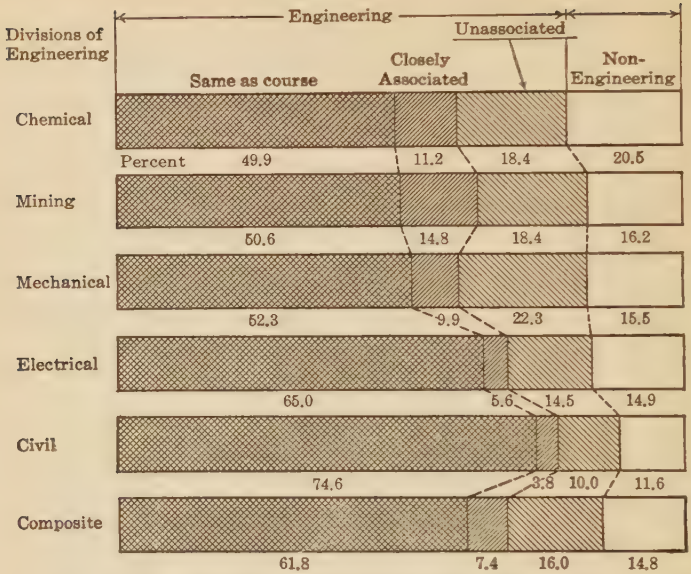


FIG. 5. Relationship of fields of work of engineering graduates to college courses

than other groups of graduates. The percentages of men in the same or closely associated fields are shown by the following figures:

TYPES OF ENGINEERS	GRADUATES OF 1922, 1923, 1924	GRADUATES OF 1919 AND EARLIER CLASSES	BOTH GROUPS
Civil engineers	85.8	71.2	73.5
Electrical engineers	80.3	56.7	70.6
Mining engineers	74.6	50.0	65.4
Mechanical engineers . . .	62.0	62.5	62.1
Chemical engineers	61.2	60.7	61.0

The foregoing evidence shows that in addition to receiving a reasonable salary, the majority are satisfied

with the kind of work which they are doing and the opportunities ahead of them.

The outstanding fact is that the earning power continues to increase for at least twenty to twenty-five years, which is in contrast with the usual trades. Besides, there is a good opportunity for advancement to executive positions, equal to that in business and with corresponding returns.

Information gathered by one corporation shows, for instance, that there are over fifteen hundred employees receiving $3000 to $4000 per year. Of those attaining this salary level during 1925, 34 per cent were college graduates, and they reached this level after an average length of service of 5.3 years. While 56 per cent were non-college men, their average length of service was 15.4 years — a time advantage of 10.1 years for the college graduate. The following table gives the facts:

Attaining the $3000 Level in 1925

Percentage of Group	Class	Average Years of Service
34.0	College graduates	5.3
9.9	College non-graduates	9.3
56.1	Non-college men	15.4
100.0		

Attaining the $5000 Level in 1925

Percentage of Group	Class	Average Years of Service
47.9	College graduates	12.0
10.7	College non-graduates	14.0
41.4	Non-college men	20.5
100.0		

In one company, college graduates constitute but 5 per cent of the total number; but they fill 30 per cent of the jobs that pay $3000 per annum, and 40 per cent of the jobs that pay $5000.

The main advantage of the graduate over the equally able or more able non-college man who reaches a position of responsibility is in the rapidity of his start. On the average it takes such a non-college man *far more than four* years to gain a background of experience that is worth as much for his progress as the graduate's college training.

While the college graduate may have a time advantage over the non-college man of over *ten years* in reaching the $3000 salary, the time advantage does not continue to increase because continued promotion depends more and more on personality and on ability to direct men. "Once well started, the non-college men with the ability to advance made as rapid progress as the graduates." College training does not provide a formula for success, but does assist in creating an early opportunity to serve and earn in positions of responsibility.

In a group of graduates of one institution, out of college five years and all employed by one company, the minimum salary was $2400, the mean was $3000, and the maximum was $4300. Differences in earning capacity were already evident, and corresponding differences in ability to carry responsibility were apparent.

But more than salary is to be considered. Is there a satisfaction in engineering work? Is the service performed a valuable one to society? Are the associa-

tions pleasant, the friendships permanent, the ideals high, and the professional standards of an inspiring character? The author believes that all these questions depend for their answer on the individual and his qualities, including adaptability to the profession, initiative, and enjoyment of creative work of this character. The great majority would answer that the work is interesting, varied, and valuable, requiring mental alertness, ingenuity, and ability to manage, to design, to do research, or to perform other useful service. The leading spirits in engineering are inspiring characters, thoroughly devoted to a life of service, devout in their attitude toward their high calling, creators of convenience, comfort, safety, health, and wealth for others.

VOCATIONAL GUIDANCE

Answer the following questions conscientiously and then consult with your high-school principal, a teacher, or an engineer.

Analyze Yourself

1. Name: ------------------------------------

2. Address: ----------------------------------

3. Father's business: ---------------------------

4. Check studies which you liked best with an X *before* the study:

Arithmetic	English	Modern language
Algebra	History	Chemistry
Geometry	Drawing	Physics

5. Check with a zero *after* the subject those which you did not like.

6. In what studies did you obtain high grades?

7. What work have you done in the summer?

8. Did you like it?

9. Do you like to use tools?

10. What have you made with tools?

11. Do you like to make or repair mechanical or electrical devices?

12. Do you like to draw or plan things to be made?

Personal Characteristics

1. Do you get along well with schoolmates and people generally? Do you work best alone or with others?

2. Do you keep at a hard job and do it thoroughly? Have you patience?

3. Are you a "quitter"?

4. Think over carefully the following list of qualities; then check your best judgment of yourself:

	Good	Fair	Poor
Carefulness			
Punctuality			
Honesty			
Initiative			
Energy			
Persistency			
Enthusiasm			
Self-confidence			
Thrift			

The form on page 38 is filled out by students as soon as they have been admitted to Purdue University. It is an excellent aid to self-analysis. Study the descriptions of the various characteristics, and then copy the chart and fill it out for your own benefit.

Personnel Forms

Purdue University is interested in developing not only your mentality, but also your character, physique, and personality.

You will soon be a student at Purdue. You can aid us and yourself in our efforts to help you derive the maximum benefit from your studies at Purdue if you will grade yourself in the qualities and characteristics of the following list.

Please place a check mark (√) after each characteristic at the place on the scale at which you believe you should be rated. If you are exceptionally good, put a check (√) under 10. If you are the poorest, put it under 1. If you have a high average, check under 6; if you have a low average, under 5; and so on through the scale. If average, place check between 5 and 6.

Grade yourself in comparison with men of similar age, educational preparation, and environment. An effort has been made to define each of the characteristics in the following list in order that greater uniformity of rating may result.

CHARACTERISTICS	POOR		LOW		AVER-AGE		HIGH		HIGHEST		
	1	2	3	4	5	6	7	8	9	10	
1. **Address and manner.** Do I leave a good impression? Do I talk well? Am I popular? Have I a good bearing?											
2. **Attitude.** Am I rational, agreeable to reason, in my views? interested in my work? optimistic? self-controlled?											
3. **Character.** Am I reliable? dependable? absolutely honest? responsible? clean? just? courageous?											
4. **Coöperative ability.** Can I work with others? Am I accommodating? loyal? willing to learn? tolerant? tactful? Am I a good mixer?											
5. **Disposition.** Am I cheerful? courteous? congenial? enthusiastic and not conceited?											
6. **Industry.** Am I a hard worker? Have I perseverance? Am I persistent?											
7. **Initiative.** Am I a self-starter? Do I recognize, start, and develop opportunities to a successful conclusion? Am I original?											
8. **Judgment.** Have I common sense? observing and reasoning power? foresight? resourcefulness? Do I know values and the relations of things? Am I practical?											
9. **Leadership.** Do I understand men and can I command their respect? Have I executive ability? Do I precede and direct men?											
10. **Native capacity.** Am I naturally accurate, systematic, bright, alert? Have I an inherent knowledge of facts and data? Can I concentrate? Do I learn readily? Have I a natural aptitude for work?											

REMARKS. Indicate under this head any additional information which may prove of value. If you have poor health, a deformity, or any peculiarity, this should be reported. Please note here.

BIBLIOGRAPHY

BAKER, ROY PALMER. Engineering Education. John Wiley & Sons, New York.

CONANT, L. W. Tackling Tech. The Ronald Press Company, New York.

DARROW, F. L. Masters of Science and Invention. Harcourt, Brace and Company, New York.

DAVIS, JESSE BUTTRICK. Vocational and Moral Guidance. Ginn and Company, Boston.

HALL, CYRIL. Conquests of Engineering. Blackie and Son, London.

HAMMOND, JOHN HAYS. The Engineer. Charles Scribner's Sons, New York.

HAMMOND, J. W. Charles Proteus Steinmetz. The Century Company, New York.

HEADLEY, LEAL A. How to Study in College. Henry Holt and Company, New York.

HORTON, C. M. Opportunities in Engineering. Harper & Brothers, New York.

LYMAN, ROLLO LA V. The Mind at Work in Studying, Thinking and Reading. Scott, Foresman and Company, Chicago.

MCCULLOUGH, ERNEST. Engineering as a Vocation. David Williams Company, New York.

NEWELL and DRAYER (editors). Engineering as a Career, by prominent engineers. D. Van Nostrand Company, New York.

PROUT, H. G. A Life of George Westinghouse. The American Society of Mechanical Engineers, New York.

PUPIN, M. S. From Immigrant to Inventor. Charles Scribner's Sons, New York.

RICHARD, T. A. Technical Writing. John Wiley & Sons, New York.

RIPLEY, C. M. Romance of a Great Factory. The General Electric Company, Publications Bureau, Schenectady, New York.

SWAIN, GEORGE FILLMORE. The Young Man and Civil Engineering. The Macmillan Company, New York.

TALBOT, F. A. The Railway Conquest of the World. W. Heinemann, London.

THOMPSON, HOLLAND. The Age of Invention. Yale University Press, New Haven.

WADDELL, J. A. L. The Engineering Profession Fifty Years Hence. Published by the author, 35 Nassau Street, New York.

WILLIAMS, ARCHIBALD. The Romance of Modern Engineering. J. B. Lippincott Company, Philadelphia.

CHAPTER III

A BRIEF HISTORY OF ENGINEERING

Among the earliest known works of an engineering character are the irrigation dams and canals which watered the valleys of the Nile and the Euphrates, perhaps about 2000 B.C. There is also evidence that a small ship canal connected the Red Sea with the lower Nile more than twenty centuries before the Suez Canal was considered.

The pyramid of Cheops in Egypt, a structure of extraordinary size, was originally probably 775 feet square at the base and 481 feet high. It contained over 3,000,000 cubic yards of stone. Some of the stones are of great size and were dragged from quarries several miles away. It is believed that ramps, or inclined planes, were built as the pyramid grew, and that up these planes slaves dragged the blocks with an expenditure of human energy which we can hardly realize.

The temples of Karnak, Edfu, Thebes, Luxor, and many others in the Nile valley represent the work of ancient architect-engineers, as the size of the columns and of the masses of stone in the pylons presented problems of strength and of transportation as well as of art. The positions which the axes of these temples

occupy certify to a considerable knowledge of astronomy on the part of these early builders, and modern studies of the temples and of astronomy serve to determine the time at which they were built.

Jerusalem, Athens, and Rome had supplies of water brought from the distant hills by aqueducts before the beginning of the Christian Era. Ruins of some of the arches can be seen in the environs of Rome, standing as memorials to those who built enduring monuments. One of them was 39.5 miles long, and another 11 miles in length. A total of 359 miles of aqueducts was built to supply Rome and about 50 miles was supported on masonry arches. The Cloaca Maxima, the great sewer which served a large part of ancient Rome and occupied the bed of an old stream, was also an early engineering work of outstanding character.

Later, aqueducts were built by the Roman engineers in the valley of the Rhone. One rises to a height of 158 feet above the stream over which it carried the water supply of Nîmes. Lyons and Metz in France, and certain cities in Spain, were supplied with water by the Romans. One of the earliest books describing engineering works was written A.D. 79 by Frontinus, a Roman surveyor and water commissioner.

The Romans were also builders of stone roads, and some of the principles of road construction which they used are still employed. Across the marshes near Rome they built up the surface, underdrained it with large stones, and then put on a wearing surface of smaller

ones. By 200 B.C. the empire had a total of 48,500 miles of improved roads, a large part of which was surfaced with stone; and the original foundation of these roads is in some instances being used today. They extended over France and the Netherlands into Germany and England.

During the reign of Napoleon there was a revival of road-building in France, and the present organization of highway administration was established. The roads were built mainly for military purposes, but they served also to improve civilian transportation over the main arteries of travel.

During the Middle Ages and the religious Renaissance the energies of the people were devoted to the construction of the cathedrals which today are the most splendid monuments of an unusual architectural development throughout Europe. Architecture is an art; but engineering throughout this period, until about the sixteenth century, was very largely an art also. Many features of the construction of the finest cathedrals, including foundations, columns, arches, buttresses, and flying buttresses, were as much engineering as architecture.

The twelfth to the fifteenth centuries were notable also for a marked change in the social order in England and Scotland. Not only were magnificent cathedrals built, but trade expanded, shipping grew, and a demand for better vehicles and better roads naturally developed. The term "military engineer" had been in

use for some time to designate the designer and builder of forts, and of roads and bridges over which troops were moved from place to place.

Civil engineering. The term "civil engineer" was, by contrast, used to designate the designer and builder of civil works, or those used in peaceful pursuits, such as permanent highways of trade and travel, waterworks, canals, lighthouses, railways, and bridges.

There is, however, little historical information about civil engineering until about the beginning of the eighteenth century. The revival of the art of building roads and bridges in Great Britain and on the continent of Europe at this period brought with it the need for a society devoted to the exchange of ideas and experiences. In 1818 the Institution of Civil Engineers of Great Britain was founded. This was the first national association of engineers, and was followed by the Institution of Mechanical Engineers of Great Britain, which was organized in 1847; the American Society of Civil Engineers, in 1852; the American Institute of Architects, in 1857; the American Institute of Mining Engineers, in 1871; the American Society of Mechanical Engineers, in 1881; and the American Institute of Electrical Engineers, which was organized in 1895.

One of the early road-builders of England was Thomas Tredgold, who in 1828 formulated the first definition of "civil engineering" as "the art of directing the great sources of power in nature for the use and convenience of man, as the means of production and

of traffic in states both for external and internal trade, as applied in the construction of roads, bridges, aqueducts, canals, river navigation, and docks, for internal intercourse and exchange; and in the construction of ports, harbors, moles, breakwaters, and lighthouses; and in the art of navigation by artificial power for the purposes of commerce, and in the construction and adaptation of machinery, and in the drainage of cities and towns."

This definition was shortened to read "Engineering is the art of directing the great sources of power in nature for the use and convenience of man"; and for a century this statement was generally accepted. In the twentieth century the management of industrial and engineering enterprises has become an increasingly important function of engineers, with the result that definitions which include "human engineering" have been presented. Henry G. Stott, in his presidential address before the American Institute of Electrical Engineers, proposed the following: "Engineering is the art of organizing and directing men and of controlling the forces and materials of nature for the benefit of the human race." When Andrew Carnegie presented the United Engineering Societies Building, at 29 West 39th Street, New York City, to the leading engineering societies of America, the definition proposed by Mr. Stott was adopted as the best expression proposed up to that time.

Among the pioneer engineers of Great Britain was

John Smeaton, a civil engineer, who built the noted Eddystone lighthouse on an exposed ledge of rock off the south coast of England about 1759. It replaced an early light built about 1703, and continued in use until 1882, when a new tower was built on another location. Smeaton was once asked by the duke of Argyll, "Pray, who taught you?" "Why," replied Smeaton, "I believe I may say I was self-taught, an' 't please your grace." This incident is told by Robert Louis Stevenson, whose great-grandfather, grandfather, and father were lighthouse-builders. "The seas into which his labors carried the new engineer were still scarce charted, the coasts still dark; his way on shore was often far beyond the convenience of any road; the isles in which he must sojourn were still part savage," says Stevenson[1] of his grandfather. This early engineer traveled twenty-five hundred miles by horse and small boat in one year to examine and report on beacons and lighthouses.

The last half of the eighteenth and the beginning of the nineteenth centuries were marked by the construction of a system of canals in Great Britain. Brindley was one of the notable canal-builders of this era. The network connected the growing industrial centers, and parts of it are still in use, though many sections have long since been abandoned.

[1] "Records of a Family of Engineers," in "Letters and Miscellanies of Robert Louis Stevenson." Used by permission of Charles Scribner's Sons, publishers.

The idea was soon adopted in America. The Erie Canal, from Buffalo to Schenectady, was first proposed in 1724, and later was supported by George Washington, surveyor and engineer, who examined the route. The canal was dedicated in 1825, and was the first long canal to be dug in the United States, totaling one thousand miles in length. It was 40 feet wide at the top and 4 feet deep, with locks 90 feet long by 12 feet wide. In 1925 two million tons of freight were carried on it, — about the same amount as one hundred years ago.

The Pennsylvania Canal Company built a waterway following in general the route of the Pennsylvania Railroad from the Susquehanna River to Pittsburgh. One of the unique and original features of this system was an inclined plane up the slope of the Allegheny Mountains by which goods and canal boats were transferred from the eastern watershed to the western near Johnstown, Pennsylvania, where the boats reëntered a canal extending to Pittsburgh. A tunnel (still intact) was built on the western slope of the mountains; and through it boats went on their way to and from the summit, which was located not far from the Horseshoe Bend of the main line of the railroad. Altogether, nearly one thousand miles of canal were built in Pennsylvania.

Considerable systems of canals were built in other states, such as the Chesapeake and Ohio, the Miami and Erie in Ohio, the Illinois and Michigan Canal; but

the railroad age was coming on apace and made many canal systems bankrupt or obsolete. Today the only projects for inland water transportation which are being prosecuted are systems of movable dams to improve navigation on the Ohio River and tributaries, and the improvement of the Mississippi and of the Missouri, Kanawha, Cumberland, and a few other tributaries; the canal period has passed.

The Erie Canal has been enlarged to a barge canal at an expense of $101,000,000, but without attracting to it any large amount of freight except local materials. There is now under consideration a plan for the improvement of the St. Lawrence River, for navigation by ocean vessels and also to develop some three million horse power of hydroelectric energy. It will require an international agreement to finance and to operate the enterprise, which, it is estimated, will cost some $500,000,000.

The Suez Canal, the Kiel Canal, the Corinth Canal, the Cape Cod Canal, the Manchester Canal (from Liverpool to Manchester), and the Delaware and Chesapeake Canal all (excepting the Manchester Canal) connect tide waters. The "Soo" Canal, between lakes Huron and Superior, like the others just mentioned, is short. It has a large through traffic amounting to seventy-two million tons of freight in the open season (of only about seven months).

The civil engineer was and is responsible for planning our highways, our canals, and our railroads. The

development of steam railroads began in the United States in 1829, when the locomotive known as *Tom Thumb* was run over what is now a part of the Baltimore and Ohio Railroad. Today there are two hundred and fifty thousand miles of main line in this country, which equals the mileage of the rest of the world.

Special rack railways have been designed to mount grades steeper than can be climbed by ordinary friction traction. Cable lines, for steep grades and also for street-railway operation, were very common before electric traction became practicable. The cable-driven street railway is now obsolete.

The St. Gotthard, Mont Cenis, and Simplon tunnels, in Switzerland, and the railway tunnels through the crests of the Rocky Mountains are notable works of the civil engineer. He is responsible also for the tunnels under the East and North rivers, New York, through which trains pass from New Jersey to the Pennsylvania Station in New York and from there to Long Island. One of the earliest railway tunnels under a large river was the Grand Trunk tunnel under the St. Clair River between Port Huron, Michigan, and Sarnia, Ontario, completed in 1890. Joseph Hobson was the chief engineer.

Among the great railway engineers, we should mention George B. Roberts, who rose from rodman to president of the Pennsylvania Railroad and was one of its greatest organizers; William J. Wilgus, chief engineer of the New York Central Railroad and largely

responsible for the conception and design of the Grand Central Station in New York; John E. Switzer, who rose from surveyor to chief engineer of the Canadian Pacific Railway and who was one of the most brilliant of Canadian railway locators and builders; Alexander Ross of Canada, who, with George Stephenson of England as consulting engineer, designed the first bridge across the St. Lawrence River. This structure, called the Victoria Bridge, is 6592 feet long and was once referred to as the "Eighth Wonder of the World."

Theodore D. Judah was the engineering genius who located the Union-Central Pacific Railway from Council Bluffs to Sacramento. The pioneer transcontinental railway was born in the mind of this daring "Railway Pathfinder," as he was called. Eighteen hundred miles of line were built in six years in the face of great natural obstacles and Indian hostility, and the last spike was driven near Salt Lake City in 1869.

The empire-builder of South Africa, Cecil Rhodes, conceived the "Cape to Cairo" railway, six thousand miles in length. This line penetrated an unknown continent and was one of the most hazardous achievements in railway finance, location, and construction. The hostility of the native tribes and the numerous wide river crossings were terrible obstacles. The bridge at the Victoria Falls of the Zambesi River is an arch with a span of five hundred feet, the track being four hundred and twenty feet above the water. On this line the world's record was made by laying five and three-

fourths miles of rail in one day with native labor. Sir Charles Metcalfe, Bart., was one of the able English engineers on this section. The bridges were designed by G. A. Hobson, and their construction is a splendid monument to all the engineers employed on this great work.

Another great railway builder was A. A. Robinson, who built the Denver and Rio Grande Railroad, which reached an altitude of 11,522 feet, — the highest but one in North America, and the most spectacular.

The Siberian Railway, which extends from Moscow to Vladivostok, a distance of 4771 miles, is a tribute to the genius of Russian engineers and to financial, political, and military vision.

The Andes railways, in South America, are other monuments to great engineers. Henry Meiggs of Philadelphia was one of these. With his successor, William Thorndike, also from the Quaker City, he built the highest railway in the world. In 138 miles it rises to an elevation of 15,865 feet at Oroya, Peru.

A significant invention was the puddling process for making wrought iron, which made possible the great development in iron and steel which marked the nineteenth century. Wrought-iron rails and the iron bridge became practicable, and engineering began to grow from an art to a science and gradually developed from a trade into a profession.

Art teaches methods of doing things and of making things, and is a matter of experience rather than of

scientific rule. An *artisan* is a skilled mechanic or one who is familiar with the *art*; a good carpenter, machinist, or stationary engineer, who knows how to carry on the work of his art in accordance with good standards, is an artisan. Engineering throughout the long period of development from the earliest times down to about the eighteenth century was an art rather than a science. When James Watt saw that by the application of a condenser additional power could be obtained from the same quantity of fuel and the same boiler and engine, he began the development of the science of mechanical engineering.

Bridges have been built from the earliest times, beginning with a tree felled across the stream and including even notable bridges which were built on the strength of experience and of past performance. The art, instead of scientific principles, determined the design.

Although a small modern steel bridge may be of the same form as the simple truss which the Roman soldiers employed, the difference is that today the sizes of members — that is, their strength — is computed from well-known scientific laws.

The development of the Bessemer converter for making steel and of the open-hearth process of manufacture has made longer bridge spans possible. Among the notable modern steel structures are the various types of truss bridges such as those over the Ohio River between Cincinnati and Covington, and between

Cincinnati and Newport, the Cairo Bridge, the Louisville bridges, and numerous other railway and highway bridges, the longest of which has a span of 550 feet.

The cantilever type makes longer spans possible and economical. One of the earliest was the Niagara cantilever, built for the Michigan Central Railroad in 1882, with a river span of 470 feet. Then in 1885 followed the St. John River Bridge in New Brunswick, with a central span of 477 feet, and in 1889 the Poughkeepsie Bridge, with a maximum span of 548 feet. The Memphis Bridge over the Mississippi River contains a fixed span of 621 feet, and two cantilever spans of 700 feet each. It was completed in 1892, at which time the great Forth Bridge, near Edinburgh, had just been finished with a span of 1710 feet. This remained the longest bridge span in the world from 1891 until about 1920, when, after several accidents, the Quebec Bridge over the St. Lawrence was finally completed, with a span of 1800 feet.

Notable suspension bridges are the Cincinnati Bridge over the Ohio River, with a span of 1057 feet; the Brooklyn Bridge, with a span of 1595 feet; the Williamsburg Bridge (completed in 1903) over the East River, with a span of 1600 feet; and the Delaware River Bridge (finished in 1926) at Philadelphia, with a span of 1750 feet,— the longest suspension bridge yet built.

Notable steel arch bridges are the Eads Bridge at St. Louis, the two arch bridges at Niagara Falls,

NORTH HILL VIADUCT, AKRON, OHIO

An example of reënforced-concrete design — a branch of civil engineering. (Courtesy of Harrington, Howard & Ash)

HELL GATE BRIDGE OVER THE EAST RIVER, NEW YORK

The longest steel arch in the world when built in 1917. It has a span of ten hundred and seventeen feet

and the one across the East River at Hell Gate. The last has a span of 1017 feet, which was completed in 1915, although the entire structure was not finished until 1917.

The railway age began with the first American line, which was put in operation in 1830. It has grown until there are now two hundred and fifty thousand miles of main line in service, and four hundred thousand miles of track. Traffic has increased in the United States to the point where a million freight cars have been loaded per week. Locomotives have increased from four and one-half tons to over two hundred and fifty tons in weight, and freight cars from a few tons' capacity to a capacity of one hundred tons or more.

The automobile and the auto truck have led to an extraordinary development of our highway system and to the expenditure of vast sums for construction and maintenance. Problems of relocation, railway crossings, bridges, curves, and grades have made the location, design, and construction of modern highways a major engineering problem requiring an amount of knowledge approaching a science.

Mechanical engineering. Mechanical engineering is that branch of engineering which designs, builds, and operates steam-power machinery, internal-combustion engines, refrigerating machinery, railway steam motive power, hydraulic pumps and turbines, and labor-saving machinery.

Hero of Alexandria is credited with the invention of a crude suggestion of the modern steam turbine, but no practical use of it was made for eighteen centuries. The earliest successful steam engine was the subject of the first recorded patent, and was largely the work of Thomas Newcomen, in England, about 1705. A number of crude pumping engines were built by him to use in draining mines. The steam was condensed in the cylinder, and a simple valve gear was arranged by the boy (named Potter) who was hired to open and close the valve which admitted the cooling or condensing water.

The development of mechanical engineering as a science begins with the improvement of the steam engine by James Watt about 1765. The subsequent refinement of it by Corliss in 1876, the invention of the steam locomotive by George Stephenson in 1829 and of the steam turbine by Parsons in 1884, and the development of the internal-combustion engine — beginning with Otto of Germany and followed by Diesel — have undoubtedly exerted the most powerful influence on civilization of any inventions or developments since the beginning of the Christian Era.

A relation exists between the ratio of total power developed to population and human welfare. The reduction of manual labor is a function of the power per person. In the United States there is 7.5 horse power per capita, in England 4.5 horse power per capita, and in Russia less than 0.5 horse power, with the result

that less physical labor is required in the United States per unit of production and that the cost is consequently reduced.

The economy with which steam power can be produced is another evidence of the contribution of mechanical engineers. The Newcomen pumping engine of two hundred years ago used twenty-two pounds of fuel for each horse-power hour produced, whereas today one pound of coal produces one horse power for one hour; thus twenty-two times as much power is produced today as could be generated by a pound of fuel two hundred years ago.

The steam hammer, invented by James Nasmyth; the cotton gin, by Eli Whitney; the spinning jenny, by Hargreaves; the spinning frame, by Arkwright; and the power loom, by Cartwright, — these inventions were followed in rapid succession by a wide variety of machine tools.

John Ericsson, of Sweden, applied the principle of the screw propeller to ship propulsion. He designed the *Monitor*, — which met and defeated the *Merrimac* in the Civil War, — invented the hot-air engine, and devised the solar engine designed to utilize the heat of the sun.

Robert Fulton was the first American to apply steam to the propulsion of a ship, and he built the *Clermont* to demonstrate its practicability to a doubting public.

Steel was first made in crucibles. Then came the Bessemer converter and the Siemens-Martin open-

hearth processes; and gradually the latter has become the recognized method of producing commercial steel. Alloys of remarkable quality for tools, for wire, and for automobile parts have been produced to meet a varied demand.

The invention and development of the automobile is the product of the genius of the mechanical engineer. He has devised and improved all kinds of labor-saving machinery, such as semi-automatic and automatic tools. He has developed steam transportation by land and by sea, refrigeration, and the uses of compressed air. Steam power and its applications to industry have exerted a powerful influence on our civilization.

Standardized, interchangeable parts and mass production are products of American engineering enterprise which have brought simplicity and economy to industry.

Electrical engineering. The early experiments of Faraday and then of Benjamin Franklin, followed later by the invention of the Gramme and Brush dynamos in 1878 and of the incandescent light by Sawyer and Edison, have led to one of the most startling contributions by the engineer to human safety, convenience, and comfort.

The invention of the electric telegraph by S. F. B. Morse, and the laying of the first trans-Atlantic cable, revolutionized communication. Then, about fifty years ago, there followed the telephone, which

Alexander Graham Bell invented. Only twelve years ago Marconi and De Forest developed wireless, or radio, communication, which depends on new scientific principles unknown twenty-five years ago. The general use of the telegraph and telephone and the invention of radio have developed a new field called communication engineering.

The field of electrical engineering now includes the design, manufacture, and application of electric generators, the latest of which are of capacities greater than one hundred thousand horse power. Motors of various types, with capacities ranging from a small fraction of one horse power to eight thousand horse power, are built and applied to all kinds of machinery and apparatus.

Electric railways provide urban and suburban transportation. Railway signaling apparatus and a multitude of other safety devices depend on applications of electricity. At the same time, they are automatic in operation, relieving men of manual labor and releasing them for other work.

This electrical age has not yet reached its climax. More men are employed in electrical research and development than in any other field. New applications are being made. Wireless-telephone communication with Europe is now a fact, and transmission of pictures by wire will probably be followed by wireless transmission of photographs as they are taken and of scenes as they occur.

Industrial engineering. The invention of machinery to replace and reduce manual labor, the design and selection of special machinery for special jobs, factory planning with a view to more economical production, the measurement of cost, and the reduction of cost have led to the scientific study of industrial methods and of management. This is one of the newest fields, called industrial engineering or scientific management.

The improvement in working conditions, the study of fatigue and of methods to relieve workers by supplying proper devices, the application of psychology to industry, and the improvement in methods of selection, training, and promotion are largely the work of industrial engineers. They have studied wage systems with a view to rewarding the skillful. Safety engineering is a related field which plans protective devices.

Chemical engineering. Chemistry has had its applications in industry for many years in increasing measure. Since the war its scope has broadened in this country; and it is the primary factor in the manufacture of explosives, dyes, and synthetic chemicals, in the paper and wood-pulp industries, and in the preparation of sugar, leather, lubricants, abrasives, and many other products.

Certain arts long practiced by the chemist, combined with a knowledge of the chemistry of fuels, rubber, cement, and other materials, have led to

chemical engineering, which combines chemistry, basic methods of reduction, and engineering knowledge, and applies them to the field of chemical production.

Mining engineering. The production and refining of precious metals is one of the oldest arts requiring knowledge and skill. Today the mining of coal, iron, copper, silver, and gold is one of the leading industries. The production of petroleum and natural gas is also in the field of the mining engineer.

Metallurgy is the study of processes of producing iron, steel, aluminum, copper, brass, and an increasing number of valuable alloys. Greater strength, greater resistance to shock, and other important qualities for use in cables, automobile parts, cutlery, and other products have been secured, and the methods of production have been cheapened. New scientific principles are being applied to produce better and cheaper fuels.

Devices for rendering mining a safer occupation have been developed by the mining engineer.

CHAPTER IV

THE COLLEGE COURSE IN ENGINEERING

The majority of engineering curricula are four years in length, but several institutions have five-year curricula in which more time is spent in pursuing liberal-arts subjects. In coöperative engineering courses the student spends about one half his time in shop, industry, or business, learning the practical side. He alternates by studying at college for one month, then taking a full-time position for a period of one to three months, and following it by a period of study of equal length at college. There are a number of institutions pursuing this method.

A few graduates continue their education after graduation by a course of post-graduate study leading to an advanced degree.

As a rule the studies pursued the first year are the same for all engineering students, because the different branches are based on the same fundamental subjects, and because certain general, or cultural, studies are included which are desirable, quite independent of the course pursued. A year is thus provided during which the student may learn more of the various divisions of engineering and make a final selection of that branch for which he seems best adapted.

A number of institutions have adopted the "freshman week," which precedes the opening of college for upper classmen. This week is devoted to an inventory of the student's abilities; it is used also in impressing the freshman with the history, organization, traditions, and rules of the college, and in teaching him how to use the library, how to care for his health, and how to study. The purpose of education is stressed, and emphasis is laid on preparation for *life* and for real citizenship rather than for earning a livelihood.

Many are being sent to college with no definite purpose. Others are going for a general education, which is commendable if they have the necessary gift. Those who go with an aim, a goal, have an interest, a stimulus, which is lacking when the student goes with no definite object in view. Without an object, interest is usually lacking; and without interest or desire but little will be accomplished. The student who has no ambition might well wait until he *has* this essential quality, rather than go to college to acquire it. Where there is no great incentive, it is better for the student to work for a year before entering college. The experience should inspire the boy with a greater desire for an education, it may help him to decide the kind of course which he desires, and it should teach him certain fundamental lessons of punctuality, obedience, perseverance, thrift, and self-confidence.

The first year. The first year is the real test of ability to master the average course leading to an engineering

degree. It is not too difficult for those who are properly prepared, industrious, and apt, but there are numerous factors which influence the result. In the first place, the high-school student has studied under the supervision of teachers, and has been under close parental observation. In college he himself determines when he shall study, what he shall study, and how he shall study. The freshman should schedule his time for study and his time for recreation. A lack of self-organization leads to time wasted and unaccounted-for.

The average engineering curriculum requires the student to attend college more hours per week than other curricula, because shop, laboratory, drawing, and design courses demand three hours of practice instead of the one hour of recitation required to obtain a credit in other subjects. A curriculum of eighteen credits requires attendance from twenty-four to twenty-six hours per week. If the average is eighteen credits per semester, and two hours are devoted to preparation for each recitation, the total time required for preparation and attendance at class is fifty-four hours per week. Some students spend more time and some less. The engineering student who does not systematize his time will find little opportunity for recreation unless the college schedules it for him, as many are doing. He will also find too little time for necessary sleep and diversion.

How to study ought not to be a problem; but it is for some. They are homesick, and the mind wanders

to other scenes. There are numerous distractions, such as "mass meetings," class meetings, and errands for upper classmen; but these are not much greater now than they have become in high school. There is the new freedom to do as one likes; and it requires time for some students to learn that, in college and out, freedom does not mean the privilege of neglecting work but is an added responsibility to do more work with less supervision.

College men are a selected group, usually representative of the best students of the high school. The rate of progress set is therefore higher than in their previous experience. It is necessary to accomplish more in one hour of study than could be required before. Furthermore, students have chosen their life work, and the incentive is greater.

Success in college requires the systematic use of time, and concentration on the lesson in hand. It is desirable that a schedule should be prepared which shows not only when each laboratory and recitation period occurs but also when the preparation for each lesson is to be made. One who organizes his own time stands a good chance of having the responsibility later of directing others. The student in engineering who cannot systematize his own time has less chance of promotion to an executive position where he is to direct the energies of others. By such specification of the time for each study, the student will find opportunity for recreation and for leisure. Failure to systematize usually

fritters away time and leaves the student always in a last-minute rush to catch up with the procession.

Concentration is the process of excluding from the mind those sights, sounds, and thoughts which distract

PURDUE UNIVERSITY STUDENT STUDY AND WORK CHART

(THIS SCHEDULE TO BE KEPT BY THE STUDENT)

Print Name Plainly in Full: Smith (Last) George (First) Robert (Middle) M. E. (School) 1929 (Class) 220 Waldron (University Address)

Hours	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	
A. M. 6:00 to 7:00	Get up at 6:00 take shower, shave and read the "Exponent"							
7:00 to 8:00	7:00 to 7:30 — Breakfast — 7:30 to 8:00 — Study Mechanical Drawing —							
8:00 to 9:00	Study Mech. Dr.	English	Read at Library	English	Study Math	English		
9:00 to 10:00	Math.	Math.	Material	Math.	Math.	Math.		
10:00 to 11:00	Mil. Tr.	Study Mech. Dr.	Mil. Tr.	Study Mech. Dr.	Business Matters	Eng. Prob's.	Sunday School and Church	
11:00 to 12:00	Read at Library	Mil. Tr.	Study Mech Dr. and English	Study Mech Dr and English	Read at Library	study Math.		
P. M. 12:00 to 1:00	—	—	Lunch	—	—			
1:00 to 2:00	Shop	Mech. Dr.	Eng. Prob's.	Mech. Dr.	Shop	Recreation	Fold Here General Reading and Recreation	
2:00 to 3:00	Shop	Mech. Dr.	Fold Here Eng. Prob's.	Mech. Dr.	Shop	Recreation		
3:00 to 4:00	Shop	Mech. Dr.	Mil. Tr.	Mech. Dr.	Shop	Recreation		
4:00 to 5:00	Shop	— Recreation		—	Shop	Business		
5:00 to 6:00	—	— Recreation		—	—	Business		
6:00 to 7:00	—	Dinner and after dinner chatting				—		
7:00 to 8:00	study Math.	Study Material	Study Math.	Study Math.	Study Math.	Social Affairs	Social and Religious Affairs	
8:00 to 9:00	Study English	Review Eng. Prob's	Study Math.	Study Math.	study Math.			
9:00 to 10:00	Study Math. or English	Study Mech Dr.	Study English	Study English	Show at "Luna"			
10:00 to 11:00	—	— Retire at 10:00			—	—		

FIG. 6. Suggested schedule for an engineering student

the attention from the lesson. Such concentration is the first requirement in gaining that efficiency by which a good student can accomplish in one hour what the average takes two hours to do with less thoroughness. A student whose mind works slowly may by concentration make good grades if he has natural aptitude and perseverance.

Be honest with yourself. If you do not know a lesson, say so; do not bluff. The good teacher detects the signs at once and has little respect for this type of student. Students sometimes think they are passing in a course, only to find that they have failed. They have deceived themselves into thinking that they know the subject when they do not, and have not taken the trouble to ask the instructor how they stand until it is too late. If in doubt, ask the instructor; even if not in doubt, ask him anyhow.

There are numerous religious, literary, dramatic, journalistic, musical, class, and other "outside" activities bidding for the interest of the student. Some students seem to think that most of their real education is to be obtained from these accessories. They are of value, but, like other good things, should be taken in moderation and with a sense of proportion. The freshman should confine himself closely to his studies until he has proved beyond a doubt his ability to carry one student enterprise and do it well enough so that it is a source of satisfaction and of self-improvement. A diversion is desirable, but the tendency is to overemphasize the value of such activities and to devote a disproportionate amount of energy to them. The student must learn to say No, when friends suggest diversion, if there is work pressing to be done.

Why students drop out of college. Of the engineering schools and colleges which reported the reasons for students' leaving college, it appeared that 38 per

cent of the students graduated; 33 per cent left voluntarily or were dropped because of failure to maintain sufficiently high standards of scholarship; a few changed their course of study; some did not have sufficient funds; 2 per cent were dismissed for bad conduct; 3 per cent left because of poor health; some left because they were needed at home; other reasons or unknown causes were indicated for 9 per cent that did not finish an engineering curriculum.

The item of greatest importance now is that one in three failed in his studies. Why? The answer is given in the following quotation and diagrams (Figs. 7 and 8) from *Bulletin No. 2* of the Society for the Promotion of Engineering Education, which show that lack of ability, combined with lack of interest, was responsible for over 50 per cent of all failures of students in engineering.

The causes given by the various institutions for the failure of students to do satisfactory work are: lack of ability or of interest, 51.2 per cent; poor preparation, 15.6 per cent; self-support, 8.1 per cent; fraternity life and social activities, 5.7 per cent; health, 4.7 per cent; undergraduate activities, including athletics, 2.8 per cent; failure to remove entrance conditions, 2.7 per cent; other [known] causes, 5 per cent; and unknown causes, 8.7 per cent.

It is a matter of common observation that many students fail in the first college year not for lack of ability but because of neglect of their studies. The majority of those who succeed during the first year are able to graduate unless finances, health, or the

need for their help at home prevents them from continuing in college.

"Dismissal for conduct" accounts for only 2 per cent of those dropped, and we are led to conclude that the

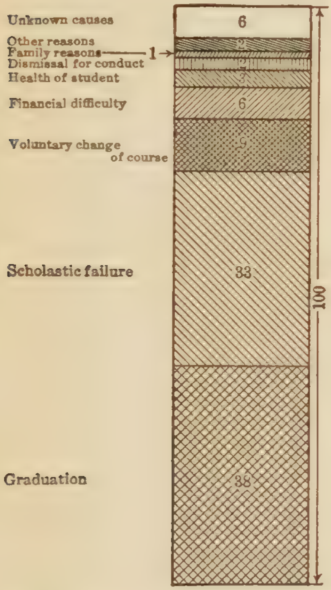


FIG. 7. Graduations and eliminations per 100 entering students

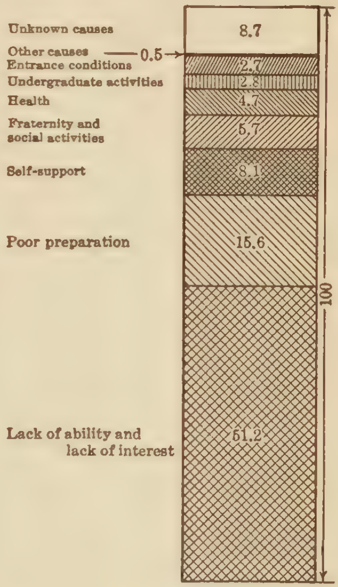


FIG. 8. Causes of scholastic failure per 100 cases of failure

present discussion about college morals is "much ado about nothing." In general, the behavior of college students is better than that of non-college people of the same age, and much better than it used to be.

It is extremely rare that a student can earn his expenses in an engineering course while in college and at

the same time maintain a high standing in his studies. However creditable it may be to earn one's own way while at college, it is a better plan for the young engineering student to remain out of college for a year and save enough to pay at least half his college expenses. Not only will he get more out of his technical course, but he will have time to enter into some well-selected student activity; and the experience will be valuable if he obtains an engineering type of job.

Good health is necessary for success in college; and definite thought should be given to some of the simplest principles, which are often neglected. A room should be selected which is properly heated in cold weather; this should be a condition made at the time of leasing or renting. Good ventilation of sleeping and study rooms should be a habit. A draft is dangerous, and can be avoided by placing a board or strip of cloth so as to deflect the air current or by lowering the top sash. A shaded light should be so placed as to illuminate the desk and not shine in the eyes. Simple food, selected to form a balanced ration and well masticated, is a necessity if the digestive system is to function properly. College students are notoriously hasty eaters; and if the choice is left to them, the food is not too well selected for its nutritive value. They need a culinary guardian or a college commons. Boarding-houses show little judgment in the selection of foods, with the result that some students are undernourished even though the amount of food may be adequate.

The *first-year curriculum,* in the majority of technical schools, is the same for all departments or courses. The first year of mathematics is a continuation of high-school courses in the same subject. The English, which usually extends through the first year, is composed of theme-writing, public speaking, or argumentation; whatever its form, it is designed to be both practical and cultural. Foreign languages are not required in all engineering-college curricula. When they are, the subject usually demands serious effort or it will prove a stumblingblock. Lack of interest, and the general tradition that the engineer does not need other languages than English, lead some to neglect foreign-language study for those subjects generally considered to be more "practical." The study of foreign languages furnishes useful mental discipline, and it is a necessity if one expects to do research in chemistry, physics, mathematics, or any other field of technical knowledge. The average student does not know yet that he will not need them for these practical purposes. Besides, there is a certain cultural value attached to the study of languages if one goes far enough to get some of the thought of other peoples. Drawing is important to all engineers; for no matter what may be the ultimate position which one may occupy, the probability is that one will be required to serve an apprenticeship in drafting. Some find their sphere in design, and almost all engineers express their ideas and give directions to others through sketches and drawings. Various other

courses are included, such as orientation and problem courses, which give the student an idea of the purpose of his training or give him a group of problems applying principles which he has already learned.

The second year. Those who survive the first year are still more highly selected, and should make higher average grades than they made in the freshman year; but this expectation is not usually fulfilled. The average grade of all sophomores is not as high as it was for the same men as freshmen. Why is this? After the first flush of victory there is a tendency to be self-satisfied and to accept mediocrity. Besides, those sophomores who are in fraternities take considerable time to discipline freshmen, and their own studies suffer while they are holding the freshmen down to "business." Watch out that you do not fail in the second year.

In the second year the study of mathematics is continued; a new and very remarkable method of analysis is unfolded. It is wonderful, beautiful, and useful. Its applications to mechanics, hydraulics, heat engineering, and electrical analysis are nothing less than startling. It has made accessible whole fields of knowledge otherwise closed to us or, at least, rendered much more difficult to cultivate.

Now the engineering student takes up physics and enters the physical laboratory for the study of physical measurements, heat, light, sound, magnetism, and electricity. These constitute a part of the

foundation on which the subsequent structure rests. Mechanics is a continuation of physics, and here the student progresses more definitely into the field of engineering problems. This is the basis of much civil engineering. Thermodynamics is the advanced study of heat on which depends the analysis of the performance of steam engines, gas and oil engines, refrigerating and air-compressing machinery. On this subject is erected the main structure of mechanical engineering.

The subject of electricity is continued for the electrical engineer.

The third and fourth years. These are devoted to the pursuit of the fundamental professional subjects, such as design, the advanced theory of structures and apparatus, the operation of the plant, and the practical economics of engineering.

Opinions of engineers. The leading engineers are insisting, in the light of their experience, that engineering schools shall include more subjects such as history, psychology, political science, economics, and English. It is necessary that the engineer be more than just an engineer if he is to be a leader: he must be a good citizen as well. The study of history teaches him the reasons for the rise and fall of empires. The broadly educated engineer can aid his generation in avoiding the mistakes of the past. Psychology helps us to understand better our fellow men, and most engineers who succeed must direct the energies of

others. Economics presents the fundamental basis on which industrial society is built. Capital, labor, property, investment, money, and trade are analyzed.

The importance of English. Many boys neglect the study of English in the high school and in college in the mistaken belief that it is not a necessity but merely something to be endured. English is of great practical value to the engineer who expects to rise above the ranks. A large number of experienced engineers of exceptional ability become executives, in which case it is necessary for them to define the work that others are to do. This requires accuracy in thinking, in speaking, and in writing. The engineer writes specifications by which great structures are built. He also draws up many contracts. These require a knowledge of the meaning of words and an ability to use them correctly. Another duty of the engineer in a position of responsibility is to present to superior officials and to boards of directors reports supporting his proposal and defending his figures. In order to present his ideas convincingly, the engineer must be able to speak clearly, concisely, forcefully, and in terms that his audience can understand, whether they are laymen or engineers.

It is deplorably rare to find young technical men in possession of an intimate knowledge of rhetoric. Business correspondence is often annoyingly protracted because one or both of the parties conducting it ignore the simple law of unity and fail to round out and complete the

subject under discussion. Errors of style and gross errors of composition are quite as frequent in the correspondence of the technically educated man as they are in that of the ordinary clerk who went to work when he left the grammar school. It is because engineers are so little accustomed to order their thought and language properly that they have so little part in the business and correspondence of the corporations which employ them. It is notorious that a technist is rarely a good business man. This is partly because of the exaggerated importance he gives to technical matters, but very largely because his thought is clumsily expressed and awkwardly ordered.

But the highest skill in the use of language is not attained when our words are properly spelled or pronounced and our sentences formed in accordance with the rules of grammar. In fact, these are only bare and absolute essentials — the skeleton of our language must still be provided with flesh and blood and nerves before it will live and fulfill its mission. The whole purpose for which language is employed is to impress our thought upon others in such a way that they shall feel or think or act as we desire.[1]

The engineer who expects to become a leader should therefore have the ability to speak and write excellent English. He needs a good vocabulary, and reading the greatest literature is the best way of acquiring it. Furthermore, the engineer needs the cultural value which is available through reading the literature of our best authors even though the experience is not directly useful in his profession.

[1] From an article by John Lyle Harrington, consulting engineer, quoted by the Society for the Promotion of Engineering Education.

High-school preparation for an engineering course. The usual requirements for entering college are three units of English; one and a half or two units of algebra, and one and a half units of geometry, including solid geometry; two units of foreign language; one or two units of science; and enough more to make fifteen units (a year's work in a subject, with recitations or lectures five times a week, constituting a unit).

Therefore the student expecting to pursue an engineering course should take the mathematics and science option in high school. Furthermore, as soon as he has made his choice he should obtain the exact entrance requirements of the particular college which he expects to attend, in order to be sure that he can meet them.

High-school principals and teachers should be acquainted with the particular requirements of the various technical colleges. The student should consult his teachers concerning his personal qualifications and aptitudes. If there is an engineer with whom the student may confer, it is advisable to get information and suggestions from him.

CHAPTER V

ARCHITECTURE AND ARCHITECTURAL ENGINEERING

Architecture is "the art or science of building, particularly the art of constructing houses, bridges, churches, and other buildings for the purposes of civil life." Often it has been called "civil architecture." Another definition is "a system or style of building, having certain characteristics of structure, decoration, etc.; as, Gothic architecture." The design which considers purpose, location, and convenience, and also proportion, style, and other factors of beauty, is good architecture.

Architecture emphasizes the artistic and decorative features in the design of buildings. The architect is an artist, and his design delights the eye at the same time that the structure may serve a utilitarian purpose. Inherent good taste and an appreciation of the sister arts of painting, sculpture, music, and literature are desirable characteristics of the architect. His work reflects the life of the people, their religion, education, business, and pleasure. As civilization becomes more complicated, as methods of transportation multiply, new materials are used, new styles are introduced, and the architect must keep abreast of changing demands.

The study of various styles or periods is important, such as the classic or Greek, the Romanesque, the Gothic, the Renaissance, the Elizabethan, the Georgian; each belongs to a particular period of civilization. Architecture reflects the ideals of the age in which the various styles originated.

The architect plans dwelling houses, — including country houses, manor houses, and apartment houses, — churches, cathedrals, municipal buildings, educational buildings, and monumental structures. The design of the modern office building has become one of the most important works of modern architects and has developed a new and distinctive type of structure, the decoration of which, if it is to possess distinctiveness or individuality, is more difficult than that of the older structure, built at a time when land was cheap and proportions were determined by the architect.

The architectural engineer. Architectural engineering is a profession which has developed in recent years as a specialized branch of architecture related to civil engineering. While the architect is concerned with the drawing of sketches, plans, and elevations, and adds the artistic touches, it is the architectural engineer who figures and designs the supporting structure and attends to its structural details.

The architectural engineer works in conjunction with the architect. Because of this relation, he must have a sympathetic understanding of the workings of the artistic mind, and must use his skill to give a visible form

to the dream and vision of the architect. It is the architectural engineer who is responsible for the design and construction of buildings which will be safe, economical to build, and efficient in operation.

The design of modern steel and concrete office buildings, theaters, and other public buildings requires careful study of the very heavy loads which the foundations and the framework must carry. This, in turn, requires a scientific analysis of the stresses caused by such loads, including wind storms, and the determination of the amount of steel which is required in roof trusses, columns, and floor structures in order that the building may be safe. There are many designs which might be safe for carrying a given load. But in addition to safety and convenience there is the question of the economical selection of the material and the design which will cost the least. Besides, there are the problems of heating, ventilation, lighting, plumbing, and power for elevators and other purposes. These all require special engineering training and experience.

Training. The average four years' course in architectural engineering includes the usual mathematics, physics, chemistry, and mechanics required in other engineering courses. In addition, the study of structures, of steel and reënforced-concrete design, is very important and is similar to that required in structural engineering. The study of heating, ventilating, lighting, and acoustics represents additional features.

Elementary courses in design for architects are also given to the architectural engineers. The emphasis is on the design of the structure for safety and economy and its proper mechanical equipment.

Registrations and licenses. Many states require all architects who are responsible for the work of their office to be registered. They must have satisfactory training and experience, and must then pass an examination before they are registered and licensed to practice. In many states architectural or structural engineers must also obtain licenses before they are permitted to practice.

In a few states all architects and professional engineers in responsible charge of work must be licensed. After being licensed, the engineer may become the structural designer or structural engineer in the large force employed by an architect, or he may become a partner of an architect. He may also establish an independent office as a consulting engineer on problems of special design. His field may be limited to steel structures or reënforced concrete, or it may include both. He may also employ specialists to plan heating, plumbing, elevator service, power installation, and other special features.

The architectural engineer may also design a great variety of industrial buildings, from factories to power plants, where very complicated structural problems enter and where safety, service, and economy are important factors.

The beginner. The graduate from a course in architecture begins his experience by tracing drawings made by others. He is then given certain studies to make preparatory to the design of details. He is perhaps assigned to a building under construction as inspector, to see that the architect's plans and specifications are carried out. The inspector makes estimates of the value of the work done each month, upon which estimates the payments made to the contractor are based.

The student expecting to pursue architecture should be artistic; that is, he should appreciate the beautiful, in the fine arts or in nature, including harmony in line and color. He should also have skill at an early age in drawing and sketching with a pencil or ink or in color. The changing demands of architecture require in the larger offices some who are business organizers and engineers. A few designers of industrial buildings are also contractors for their construction.

Young women have long since entered the fields of interior decoration (including mural decoration and house furnishing), and have succeeded in these fields. Today a few young women are pursuing architecture with the intention of becoming designers or decorators. A field exists where a woman may anticipate feminine tastes, especially in furnishings, draperies, and other details.

Architecture differs from the usual engineering course in that less mathematics and science are required

and more liberal culture. The study of French and history is more important. Moreover, the student of architecture begins elementary design in his first year and continues it throughout the four years. The study of geometric forms, of shades, of shadows, and of sketching begins in the first year. The use of water colors and oil painting are also part of the instruction, their purpose being to develop the artistic sense and an appreciation of color effects and harmonies. A large amount of time is devoted to wash drawings, which present to scale and in perspective a proposed design. In addition, there are detailed floor plans, drawings, and sketches for the guidance of the contractor. The course includes the strength of materials, simple studies in the strength of structures, — as, for example, those of timber, steel, and concrete, — building inspection, bills of materials, contracts, and specifications.

An architect may be a good draftsman, business man, and organizer; but he must also be an artist, with imagination and an appreciation of beauty.

The superintendent of construction approves or disapproves materials and methods of construction (including protection in freezing weather), makes changes in the design (if necessary), and authorizes extra work and the basis of payment therefor. He may return to the office and do planning or designing either as chief of design or as an independent architect. There is a tendency to specialize on planning, design, equipment,

or construction, and each large office has its experts in these fields or consults specialists.

The young architectural or structural engineer may have much the same experience during the first few years.

Each may begin by tracing drawings made by more experienced men; each may serve as inspector or superintend the construction of a building. The architect then takes up the æsthetic problems of design, studies the different orders or styles, the adaptation of appearance to use or convenience. The young architectural engineer devotes himself to the study of the strength, durability, and economy of materials, designs columns, girders, and trusses to support the structure, and attacks problems of erection, makes bills of materials needed, and estimates costs.

CHAPTER VI

CIVIL ENGINEERING

The earliest works of the civil engineer were roads and bridges. Later in the development of civilization came systems of water supply, drainage, canals, harbor works, railroads, tunnels, and buildings.

The modern civil engineer makes the preliminary surveys, prepares maps, designs, specifications, contracts, estimates of cost, and reports on a wide variety of projects. He prepares detailed drawings, inspects and superintends construction, and often operates the works which he has designed. Some engineering firms finance the projects which they build.

The young civil engineer may find employment in one of three general classes of work: first, field work; second, design; and third, operation.

Field work includes surveys of proposed highways and, to a very limited extent, of railways; resurveys for improvement of line or grade or both; laying out of buildings or bridges; and inspection of the construction, improvement, or repair of various structures. A considerable portion of the time, even in severe weather, may be spent out of the office, away from cities, — in places where living conditions may be crude. A good field man must adapt himself easily

to conditions and must get along well with all kinds of people. Field experience is valuable and should be obtained soon after graduation.

The second division, called *design,* is largely office work and includes drafting, mapping, computing, and the actual design of structures. Those who advance in the design room do the work of chief draftsmen, estimate costs, prepare bids, and direct the work of other draftsmen.

The third division, called *operation,* includes the management phases of civil engineering. Engineers of maintenance of way on our railroads are in supervisory positions; district engineers in state departments of highways are directing the work of others. Civil engineers are appointed as city managers and city engineers, where they are concerned more with financial and human problems than with engineering problems. In small cities or with small companies, one engineer may make the necessary surveys and designs, estimate the cost, and recommend that the work be undertaken or not.

The city commissioner in charge of a water-works system, a sewerage system, street cleaning, or similar work is an operating engineer. The superintendent of a water-filtration plant is an operating engineer, although technical ability may be as necessary as managerial ability.

Civil engineering has become specialized, and one person cannot become an expert in each of its branches.

The following divisions will be discussed briefly:

- Highway engineering
- Railway civil engineering
- Municipal engineering
- Hydraulic engineering
- Sanitary engineering
- Structural engineering
- Bridge engineering
- City planning
- Surveying and geodesy

Highway engineering. The modern highway engineer has a much more complex problem than his predecessors had. The automobile, the auto truck, and the auto bus have created new conditions. Highway engineering includes location of new roads, and the relocation of old routes to avoid grade crossings, sharp bends, bridges, and traffic congestion. Road-building materials and the economic design of highways to suit the nature and quantity of traffic carried and expected are receiving serious attention. Road-traffic census data and the analysis thereof determine widths of improved roads. Economy in construction and maintenance — including the questions of interest and sinking fund on both bonds and cost of repairs — is of great importance.

The inspection of construction, cost studies, causes of deterioration (including effects of heavy trucks on wear), and safety devices are receiving careful study. The Bureau of Good Roads at Washington and the state departments of highways are the chief investigators and have influenced practice to a marked degree.

A few technical colleges and universities offer four-year curricula in highway engineering; but many more

provide a basic curriculum in civil engineering, with a highway-engineering option in the junior and senior years. The latter provides elective courses in road materials, including laboratory tests of brick, stone, concrete, bitumens, asphalts, and road oils and tars. Surveys, maps, plans for drainage, and earthwork, designs for culverts and small bridges are prepared. Specifications are written, and costs are computed. The four-year curriculum is a more specialized course and may include, in addition to the above, instruction in preparing a traffic census, economic studies comparing the annual costs of different types of highways, and a study of motor transport and of highway-office organization and administration.

The graduate who enters this field is usually assigned to a surveying corps, to mapping surveys, to earthwork computations, to the inspection of road oiling, or to office work. If he has ability and the necessary personal qualities of energy, initiative, agreeableness, and integrity, he may be promoted to the position of chief of a survey party, inspector of construction, district supervisor, or engineer. The organizations in the larger and wealthier states include several hundred rodmen, chainmen, inspectors, draftsmen, together with district, supervisory, and administrative engineers.

Just at present far greater sums are being invested annually in improved highways than were ever spent before on canal or railroad construction in the same period of time. The population is larger, the nation is

wealthier, and the demand has arisen suddenly in all parts of the country.

Railway civil engineering. The civil engineer is employed on railways in the maintenance-of-way department, or else in the main offices, where he is intrusted with bridge and building design and with real-estate, relocation, double-tracking, and other general problems.

In maintenance work the young engineer is engaged on surveys, the realigning of tracks, the laying out of new sidings, problems of drainage, real-estate boundaries, office records, and office studies required in recommending improvements. The engineer of maintenance is in responsible charge of track work, culverts, bridges, buildings, and signals and other safety devices. His position is an important one, and the most successful have an opportunity for promotion to higher operating and executive positions.

Civil engineers are employed also, in limited numbers, on electric urban and interurban lines; but new construction is rare, since the motor bus has largely forestalled the extension of suburban and interurban electric lines.

Municipal engineering. The average city engineer is responsible for the construction of roads, pavements, and sewers, the extension of the municipal waterworks system, the street-lighting and street-cleaning systems, and the disposal of garbage.

His duties are varied, and require considerable

experience as well as a broad engineering education. The demands made on him by the city council, the mayor, or the various municipal boards and commissions, as well as by citizens, are such as to call for much more than engineering skill. Fortunately the tendency now is to remove the position of city engineer from politics; but in many cities he is still a political appointee, and his tenure of office is uncertain. In either event, tact is an essential ingredient; and human engineering, — or applied psychology, — common sense, and economic sense are invaluable and indispensable to the successful municipal engineer.

The usual college course in civil engineering, with such electives as are offered in this field, offers sufficient experience in surveys, the laying out of work, inspection, and estimates; the reading of technical journals is necessary to the beginner. After that it is largely a question of opportunity and fitness for the position, — a difficult and an important one.

Hydraulic engineering. Irrigation canals, and crude devices for raising water, were used in Egypt, Assyria, Palestine, and China long before the beginning of the Christian Era. Dams, reservoirs, and canals were built in India, Ceylon, northern Africa, France, and Spain in more recent times.

Under the support of our Federal government, irrigation in the Western states has developed a number of large enterprises which water immense areas of

good soil. The measurement of water resources and of the amount of water used, the determination of the quantity of water required for various crops (including fruits), the design of dams, reservoirs, canals, and irrigation ditches, and the handling of drainage are problems for the irrigation engineer. For the present the development of arid and semi-arid lands is not in great demand.

The reclamation of swamp lands and the control of such rivers as the Mississippi and Missouri, which are subject to destructive overflows, have been closely related to the development of parts of the Mississippi Valley. Vast areas of rich lands have been brought under profitable cultivation.

The necessity for flood-protection works has become apparent as a result of the study of recurring heavy rainfall in connection with other conditions. The Miami River at Dayton, the Scioto at Columbus, Ohio, the Wabash, and the White River at Indianapolis have proved very destructive, and hydraulic engineers have protected affected cities by various types of works.

The hydraulic engineer has been responsible for the development of water power and the apparatus necessary to its utilization. The design, construction, and use of pumping machinery, and of devices for measuring the quantities of water used and the power developed or required, are a part of the work of the hydraulic engineer.

Hydroelectric power plants include the dams, controlling apparatus, water turbines, electric generators, transformers, electric-measuring instruments, and transmission lines necessary for the utilization and distribution of the water power which is transformed into electrical energy.

The earliest water wheels were actuated by the velocity and consequent energy of natural streams; then low-head dams were built, and finally the overshot water wheel, which grew to a maximum head and diameter of wheel of eighty feet. Various designs of high-head water wheels were developed in France and then in the United States, and the latter types are now in general use all over the world.

Some twenty-five million water horse power of potential energy is available in this country; but only about one fourth has been developed, and some is remote from markets, or else the cost of development is too great to warrant its use until power from coal and oil has become more expensive through a decrease in the visible supply.

In college the student of hydraulic engineering receives instruction in the fundamental subjects of civil engineering, including the principles of hydraulics, the methods of measurement used to determine quantities of water, velocities, heads, and energy, and a laboratory course to illustrate the various principles and methods. In addition, there is the study of various designs of water turbines and their characteristics and

efficiencies. The design of dams and of the various works necessary to develop water power is also included.

At present the number of water-power plants under construction is not large; but the beginner might be employed on construction to lay out the work, to inspect it, to keep a record of the time and costs, or to take charge of a portion of the work. His advancement would be from construction to surveys, to general planning, and finally to the design of details of the complicated work involved in a modern hydroelectric power plant.

Sanitary engineering. The earliest sanitary code is that in the Book of Deuteronomy. In Biblical times fire was used to destroy houses where pestilence had existed. Through the Middle Ages filth collected in public places, and epidemics swept away thousands. The Black Death of the fourteenth century took one fourth of the population of England.

Even as late as the beginning of the nineteenth century, adequate sewers and protected public supplies of water were rare. The only public sewers were the gutters, and the town pump was the chief source of drinking-water. Only a few of the larger cities had made any attempt to protect the water supply. London had a small municipal supply, carried from springs by lead pipes, as early as 1235. Boston received a supply from springs by gravity as early as 1652. Philadelphia was the first to use steam pumping machinery to deliver water (1800).

Typhoid fever, malaria, yellow fever, smallpox, cholera, and many other diseases which have been the scourge of the human race have now been reduced or practically eliminated through the efforts of preventive medicine and sanitation. Pasteur, of France, was the first to demonstrate that disease could be communicated by invisible organisms called bacteria. Koch, of Germany, proved the existence of the bacillus of tuberculosis by which the disease is conveyed from one person to another.

George E. Waring, of New York, was one of the first sanitary engineers in America. His greatest work was the sewering and general cleaning up of the city of Havana, Cuba. There he contracted yellow fever, which cost him his life, as it had the lives of thousands before him. Now yellow fever is comparatively rare in cities with proper drainage, mosquito extermination, and sanitary codes.

Through water and milk and other foods, typhoid fever has been carried from those afflicted to others. Proper inspection of public eating-places, protection of the milk supply, and prevention of pollution of the public water supply at its source, or else subsequent antiseptic treatment, have reduced the typhoid rate from an unbelievably high percentage to the low rate of two or three per hundred thousand.

Sewage which flows into streams causes pollution, foul odors, and disease if the streams are used as sources of drinking-water for human beings. Methods have

been devised to reduce or remove the hazard as conditions and the law may demand. As water taken from streams is rarely free from pollution or from danger of pollution, the filtration of water, and treating it with chlorine to render it practically free from bacteria which transmit disease, are now common. The Lawrence Experiment Station of the Massachusetts Board of Health was one of the first to study the effects of water filtration. It began its work in 1890, and much of the development of the modern art and science of sanitary engineering belongs to the period of thirty-six years since that time.

The sanitary engineer designs systems of drainage and sewers, provides for the collection and disposal of garbage by feeding, by burning, or by a process which recovers certain chemical products and makes a valuable fertilizer.

The sanitary engineer has first the basic training of the civil engineer in mathematics, surveying, mechanics, the construction of steel and concrete bridges, and electrical and mechanical engineering. In addition, he studies biology, the design and construction of sewer systems and water works, the treatment of sewage, the filtration of water, and garbage collection and disposal. The beginner gets his first experience in making surveys, laying out the work, and inspecting construction. He may then do planning, estimate costs, compare the costs of different plans, study the details of more complex works, and direct the draftsmen in the prepara-

tion of plans and specifications. There are opportunities for him in the employ of the United States Bureau of Public Health, the engineering corps of the various state departments of health, the municipal government of the larger cities, and firms of sanitary engineers.

Structural engineering. The study of steel, concrete, and reënforced-concrete structures is called structural engineering. It is almost identical with architectural engineering, except that the latter emphasizes more the artistic aspects of structures and the methods of the architect in preparing perspective and wash drawings for presentation to clients.

Structural engineering is a branch of civil engineering and has for its foundation the same drill in mathematics, physics, and mechanics. It requires an extended study of the design, construction, and inspection of bridges and buildings, including the sanitary, electrical, and mechanical equipment which may be needed.

Bridge engineering. Bridge engineering is a special branch of civil engineering, and is closely related to structural engineering. It includes the designing and construction of steel and reënforced-concrete arches and bridges, and a study of the foundations and equipment of the various types of movable bridges. The arch-girder, truss, cantilever, and suspension types are used, depending on the location and conditions.

After the technical courses in the theory and design of structures, the graduate who desires to specialize in bridge engineering should enter the drafting room

of a firm of bridge designers or builders to obtain experience in design. Next he should become familiar with shop, or fabricating, methods in connection with steel bridges. Field experience in inspection and erection should follow.

City planning. Emphasis on parks as breathing spaces for growing cities, and on appreciation of the artistic in city buildings and their location, together with traffic congestion and the general acceptance of "zoning" (in order to separate business from residential areas), has given rise to city planning as a profession.

Preparation for this profession includes a knowledge of surveying, landscape architecture, and building codes, the planning of parks, playgrounds, and civic centers, and a study of traffic of all kinds.

Surveying and geodesy. All students of civil engineering and its several branches receive instruction in elementary surveying, such as leveling, running and relocating property lines, highway and railway surveys, and methods of obtaining and plotting topography, or "the lay of the land," including both plan and elevations of important features of the landscape. In the majority of technical schools students in electrical, mechanical, and other divisions of engineering receive instruction in the use of surveying instruments and in the methods of laying out work.

Beyond this elementary work in surveying incident to construction, there are two fields of practice. These are general surveying, city and government surveys.

The first includes the work of county surveyors and county engineers in land and road surveys, drainage, and culvert and small-bridge work; also preliminary surveys for railways, irrigation projects, etc., including location and the staking out of work. The surveyor obtains the information necessary for the engineer and carries out his orders. The mining surveyor lays out claims, and makes surface and underground surveys for mining operations.

The government carries on a variety of work requiring the services of surveyors. The Coast and Geodetic Survey employs them in surveys of harbors, channels, and the coast line, in preparing maps and charts, and also in deep-sea soundings.

The United States Geological Survey obtains the topography and geology of large areas. It has carried systems of triangles called triangulation from the Atlantic to the Pacific coast and has covered considerable parts of many states. This requires great accuracy, applications of astronomy, the use of trigonometry and advanced mathematics in the computation of latitude and longitude, and the determination of probable errors in the results. The resulting maps have been of great value in mining, in railway and highway location, and in studies of watersheds with respect to water supply and water power. This higher government surveying is called geodesy.

CHAPTER VII

ELECTRICAL ENGINEERING

Electrical engineering is the youngest of the major engineering professions. The first practical application of electricity and magnetism is found in the early telegraph systems which followed the discoveries of Professor S. F. B. Morse, shortly before the year 1840. The telegraph remained alone in the field until, in 1876, Professor Alexander Graham Bell exhibited the first workable telephone. A few years later followed the pioneer work of Edison in the development of the electric generator and the incandescent lamp.

Following the year 1893, when at the Chicago Exposition the possibilities of transmission of energy by alternating currents, and the progress already made in the lighting, transportation, and communication fields, were widely shown, began what has frequently been called the Electrical Era. To the marvelous inventions and developments of this period the United States has made outstanding contributions. So far-reaching have been the results of the discoveries and inventions in the realm of electricity that the lives and habits of all civilized peoples have been markedly influenced by them. Without these inventions modern industrial development would have been impossible.

The most important fields in which electrical engineers are engaged are the generation, transmission, and distribution of electrical energy; transportation (trunk-line, urban, and interurban); communication (wire and radio); illumination (exterior and interior, practical and decorative); electrical manufacturing; and miscellaneous electrical applications in industry, commerce, and home life.

In the field of generation and transmission of electrical energy great progress has been made, and many changes of an important character are now taking place. The interconnection of some of the largest generating stations, often located many miles apart, into single superpower systems is one of the newest developments. Increased voltages have made possible the transmission of electrical energy over many miles of elaborate and carefully designed transmission lines, whereas in metropolitan districts cables carrying a very low voltage may be placed in ducts under the city pavements. Distribution systems have become so extensive and complex that closely woven networks of conductors literally cover the congested areas of the larger cities. Automatically operated substations, without human attendance, and new methods of protection and control have introduced additional and interesting problems in this field.

Utilization of electricity in transportation was first confined to urban and interurban surface lines and to the signal systems in use on railroads. Later came

electric propulsion on elevated and subway lines, and finally the complete electrification of sections of important trunk lines and their terminals. Financial readjustments, following government operation of the railroads during the war period, checked to some extent projected electrifications; but renewed activity may be expected during the next few years. Electric-train control now being required by the Federal government has brought new problems to the railway electrical engineers.

Amazing developments have occurred during the past two years in communication by telephone, telegraph, and radio. Great telephone systems have made it possible for one subscriber to communicate almost instantly with any one of millions of other subscribers. The demand for telephone service is increasing at such a rapid rate that telephone companies are being forced to replace girl operators in exchanges by automatic switching machines. These machines are exceedingly complex and may well be said to possess "mechanical brains." As a result of the installation of machine switching systems, a much larger number of technically trained supervisors are required than in the older manual systems.

The substitution of underground telephone cables for thousands of overhead wires has required rare engineering skill, and the constant increase in the distance over which telephone conversations may be carried on has multiplied greatly the problems of the

telephone engineer. Developments in radio telegraphy and telephony are among the most amazing inventions of the age. All parts of the world are now within easy communication by telegraph, and the recent accomplishment of transoceanic telephony has established regular telephone service between Europe and America. Wire and wireless transmission of pictures, television, and wireless-telephone communication with ships at sea and with airplanes are among the problems interesting experts in this field. A demand now exists in this branch of electrical engineering for well-qualified engineers who can handle the many problems resulting from the rapid expansion of the telephone industry.

Experts in illumination are recruited almost entirely from the ranks of electrical-engineering graduates. The conversion of electrical energy into light, the designing and manufacture of light sources and reflecting media, together with the correct planning and installation of lighting systems, fall within this field. The electric lighting of streets, homes, factories, and buildings of all kinds has greatly improved the living and working conditions of our people. Electric illumination has become an art which is applicable in the home as well as in the beautiful and spectacular lighting of show windows, public buildings, theatrical productions, and exhibitions. This branch of engineering offers exceptional opportunities to the engineer who possesses artistic abilities.

Almost countless different types of electrical apparatus are necessary in electrical-engineering work. This has led to the development of an enormous manufacturing industry. Such apparatus varies in size from minute devices to monster dynamos and locomotives, and in complexity from common lamp bulbs to automatic telephone-switching machines. The design, development, manufacture, testing, sale, and distribution of this equipment demand the services of large numbers of well-trained engineers.

It should be evident from this brief description that the electrical-engineering profession includes men of many talents and qualifications, engaged in many different fields of activity. The scope of electrical engineering is so broad that each engineer usually confines his efforts to one field of activity in but one branch of the profession. These fields of activity can be referred to only briefly here.

Many electrical engineers are engaged in design, drawing up the plans and specifications which must be followed in the manufacture and installation of electrical equipment. Others are engaged in research, conducting experiments in an attempt to discover unknown properties of materials which might be utilized in the different branches of the industry. Another group is occupied with development work, carrying out investigations for the purpose of devising new and improved types of equipment or methods of application.

Eta Kappa Nu, an honorary electrical-engineering

fraternity, has supplied valuable information concerning its alumni for the investigation of engineering education. In reply to a questionnaire about the kind of work, the financial distribution, and the income received by electrical workers, replies were received from a total of nearly two thousand persons, some of whom, however, may have reported twice.

OCCUPATIONS AND EARNINGS

Distribution in various kinds of activity. The kinds of positions and fields of activity of graduates are factors to be considered in many of the problems of engineering education. In the past, accurate knowledge in this regard has been meager. Guesses and opinions have too often been advanced as facts. A statement which is often heard, for example, is that over half of all engineering graduates leave engineering work for other fields. The results of the present study indicate quite the contrary. The distribution of graduates among the several functional types of activity (research, design, supervision, management, commercial, etc.) is of special importance. The data which are summarized in the following tables and diagrams give an unusually clear picture of this situation in the field of electrical engineering.

It is apparent from the table on page 102 that big industry, in the field of electrical engineering at least, absorbs a large proportion of the engineering graduates of the country since more than half of the alumni members of Eta Kappa Nu are employed by large industrial concerns or public utilities. It also appears that a larger proportion of electrical-engineering graduates are employed in elec-

trical manufacturing than in any other principal division of the field. It should be remembered in examining figures that a considerable proportion of the miscellaneous group have left the field of electrical engineering and are employed in other lines of work. It is therefore probable that more than one half of those who do remain in electrical-engineering work are connected with manufacturing concerns.[1]

BUSINESS CONNECTIONS OF ETA KAPPA NU ALUMNI

	Number	Percentage	Total Percentage
Power production and transportation			
Large central stations	140	13.0	
Small central stations	24	2.2	
Electric railways	17	1.6	16.9
Communications			
Telephone-operating companies	155	14.4	
Telephone-manufacturing companies	68	6.3	20.8
Electrical-machinery manufacturing			
Large electrical manufacturing companies	191	17.8	
Medium-size electrical manufacturing companies	55	5.1	
Small electrical manufacturing companies	15	1.4	24.3
Miscellaneous manufacturing	121	11.3	11.3
Contracting	37	3.4	3.4
Miscellaneous			
Teaching	53	5.0	
Government employ	26	2.4	
Jobbers	17	1.6	
Unclassified	154	14.3	23.3
Grand totals	1073		100.0
Total in manufacturing and contracting	487		45.3
Total in public utilities	336		31.3
Total in miscellaneous activities	250		23.3

[1] From *Bulletin No. 8* of "The Investigation of Engineering Education," The Society for the Promotion of Engineering Education. November, 1926.

Fig. 9 shows the distribution of Eta Kappa Nu alumni in "electrical engineering, other engineering, and non-engineering" fields. Of the entire number, 61.4 per cent are in the same field as their college course, 22.1 per cent are in other engineering activities, and 16.5 per cent are in non-engineering activities.

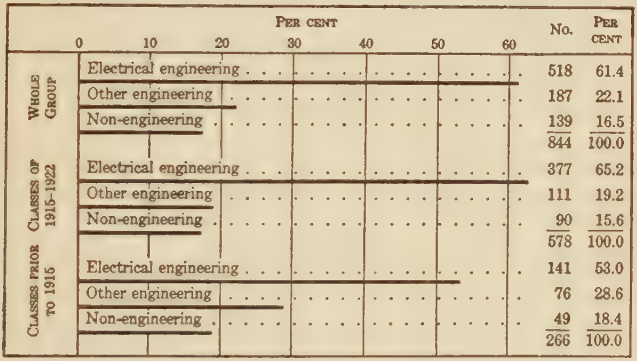


FIG. 9. Occupational distribution of Eta Kappa Nu alumni

These figures differ slightly from those compiled for the graduates of all engineering courses. The Eta Kappa Nu figures show a larger proportion in the same field as their college course (61.4 per cent against 56.7 per cent), about the same proportion in other engineering work, and a smaller proportion in non-engineering work. It is interesting to note that the members of the older classes show a smaller percentage in electrical engineering. This is to be expected, and it may be considered a normal and healthy condition.

Figs. 10 to 13 show the distribution of electrical-engineering graduates in various functional activities. The data have been grouped in a few rather than a large number of classifications: (1) technical, including such activities as designing, research, testing, and inspection; (2) operation and maintenance; (3) administrative activities, including executive direction, management, and the like; (4) commercial activities, including sales; (5) other activities. These diagrams are worthy of careful study. One feature of the diagrams is especially striking, namely, the relative proportions of the several groups who are engaged in work which is primarily administrative in nature. It should not be assumed, in considering this feature of the diagrams, that positions of an administrative nature involve greater responsibilities than other types of positions.

Distribution by functions in electrical engineering. Fig. 10 shows the distribution in five groups of functional activities of Eta Kappa Nu alumni who are engaged in the field of electrical engineering. The first part of the diagram shows the distribution of the entire group, and the second and third parts show the distribution of graduates of recent and of older classes. It will be noted that 12.7 per cent of the entire group are in administrative work and that 42.9 per cent are in technical work. The diagram shows that administrative work attracted a larger proportion of men from the older classes than from the recent classes.

This gain in the administrative group is at the expense of the technical group and the operation-and-maintenance group. There is a small increase in the proportion of graduates in commercial work.

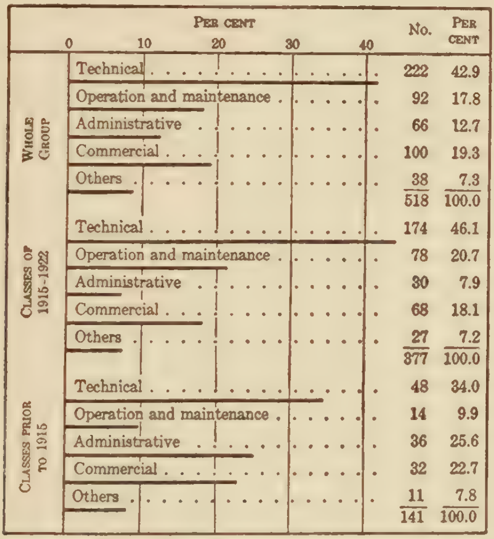


FIG. 10. Occupational distribution in various functional activities of Eta Kappa Nu Electrical engineering group (61.4 per cent of the entire number). See Fig. 9

Distribution by function in other engineering fields. Fig. 11 shows the same analysis for men in *other* engineering fields. The same shift from technical activities and operation-and-maintenance activities to administrative work is indicated. There is about the same proportion of graduates of recent classes in commercial activities as in the case of older classes.

Distribution by function in non-engineering fields. Fig. 12 shows the same distribution for those in non-engineering activities. As might have been expected, none of the members of this group is in technical work,

		No.	Per cent
Whole Group	Technical	48	25.7
	Operation and maintenance	22	11.8
	Administrative	66	35.3
	Commercial	24	12.8
	Others	27	14.4
		187	100.0
Classes of 1915–1922	Technical	26	23.4
	Operation and maintenance	15	13.5
	Administrative	36	32.4
	Commercial	14	12.6
	Others	20	18.1
		111	100.0
Classes prior to 1915	Technical	22	29.0
	Operation and maintenance	7	9.2
	Administrative	30	39.4
	Commercial	10	13.2
	Others	7	9.2
		76	100.0

FIG. 11. Occupational distribution in various functional activities of the "Other engineering" group of Fig. 9

and only a small number are in operation and maintenance. Over half of the entire group are in work of an administrative or executive nature.

Comparative distribution by function. Fig. 13 shows a comparison of the distribution of the men in electrical engineering and in non-engineering occupations. In order to make the comparison more distinct,

operation-and-maintenance work has been grouped with technical work, and the proportions in commercial and "other" activities have been grouped together. The comparison of proportions in the technical group

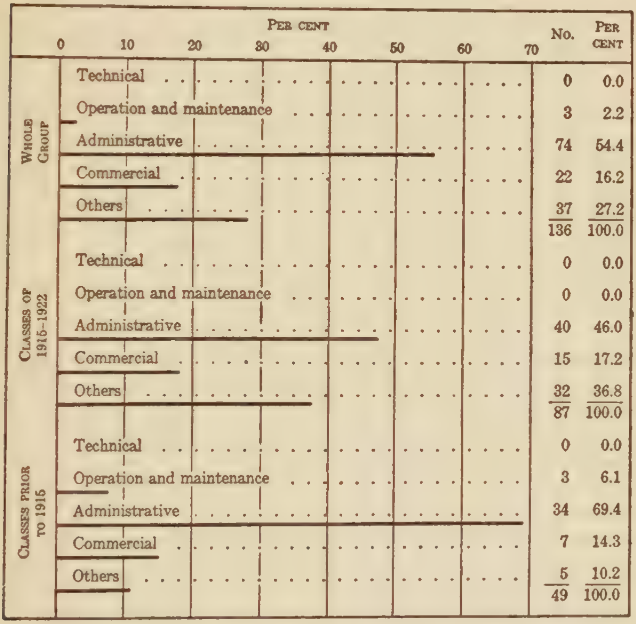


FIG. 12. Occupational distribution in various functional activities of the Non-engineering group. See Fig. 9

and in the administrative and executive group is extremely striking and suggestive.

The fact that technical work of design, research, and the like is entered by a large majority of the graduates, and that work of this character is the

normal starting place on the road to promotion to positions of administrative responsibility, is clearly indicated. It is to be expected that the proportion of graduates in the non-engineering group who are in administrative work would be greater than the proportions in the other groups. Again, it must not be

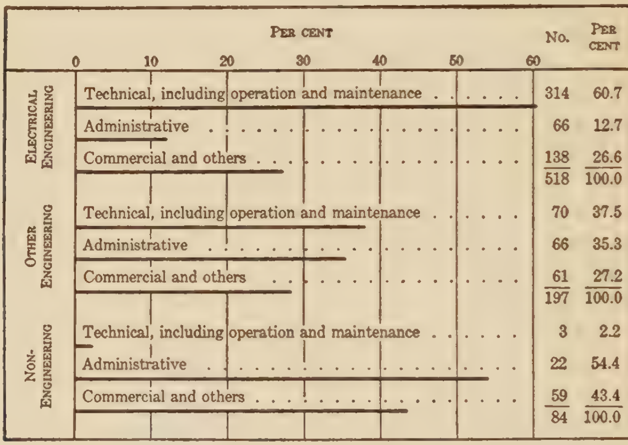


FIG. 13. Comparative distribution of the three groups of men in functional activities

assumed that positions designated as administrative are of greater importance or involve greater responsibilities than those designated as technical; in fact, the reverse is generally the case with the positions occupied by the younger graduates.

The rapid growth of the electrical industry and the increasing breadth of the field has brought with it a growing demand for graduates with sound training in

this field. The opportunities have been and still are exceptionally attractive. Advancement has been rapid for those who were capable and who also possessed those qualities of personality and character which are indispensable in the good supervisor or executive.

They vary from highly scientific positions such as those in research to those of a business or financial character. The largest research laboratories are supported by the electrical industries. There are also the fields of apparatus design, manufacturing, application, sales, and supervision. In the telephone service there are traffic and personnel, construction and operation. Central-station design, public relations, extension of service, are other lines of development which offer a future to the young, aggressive, capable, reliable, and *likable* graduate in electrical engineering who has the knack of "getting along with people."

CHAPTER VIII

MECHANICAL ENGINEERING

The world today looks to the mechanical engineer for its supply of power. Of equal importance is its reliance upon him to design, build, and operate machinery and appliances to convert the raw materials of nature into useful products. In the half-century since mechanical engineering has been recognized as a profession, progress in its many fields has been greater than in all the ages preceding; on land and sea, in every household and public building, and in the development of industrial plants the mechanical engineer has revolutionized our ways of doing things and raised the standards of living. Whether the power is obtained from the burning of coal under a boiler, from the falling of masses of water, or from the combustion of gasoline or oil in an internal-combustion engine, the mechanical engineer is charged with the duty of converting these sources of energy into forms of motion available for doing useful work. His occupation is to design and construct the necessary machines and devices, to supervise their operation, and constantly to improve them so as to get the maximum advantage with the least expenditure of time, money, and human effort. When power has been made available for doing useful work, it is the

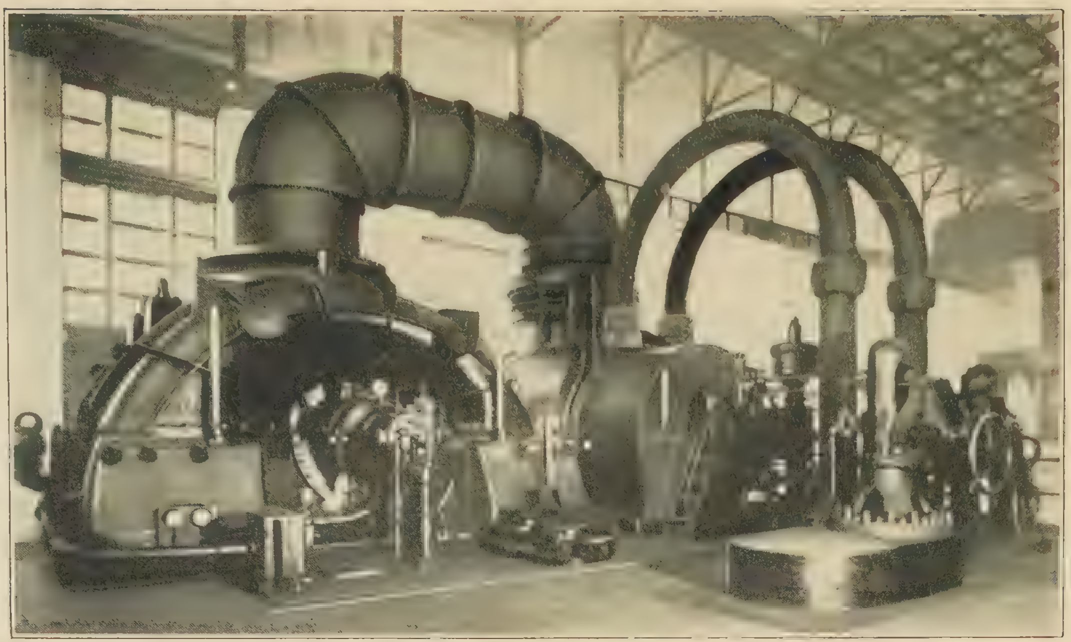
mechanical engineer who devises labor-saving machines and apparatus to transform raw materials into products for the comfort and well-being of the human race.

The machines and devices that engage the attention of the mechanical engineer today are of recent development; but the principles on which they operate have been known for centuries, some of them from remote antiquity. Long before the Christian Era the energy of a running stream of water was applied to grind corn, thus releasing the slaves of that day for other work. About 200 B.C., Hero of Alexandria described a method for opening the temple doors by the action of fire on an altar, an ingenious device which contained all the elements of the "atmospheric engine" which the marquis of Worcester perfected in 1712. It was this later machine which James Watt, in 1774, developed into a steam engine, with its essential details of the modern reciprocating engine. Hero also described a device in which steam issued from a reaction wheel; but it was over eighteen centuries before Sir Charles Parsons, in 1884, built the first successful reaction steam turbine.

Years are required to find out the shortcomings of such a machine as the steam engine; so the world waited until 1876, when George H. Corliss exhibited his first steam engine, which was one of the features of the Centennial Exposition at Philadelphia in 1876. This machine showed that steam engines could be built in quite large units; for the engine at the Cen-

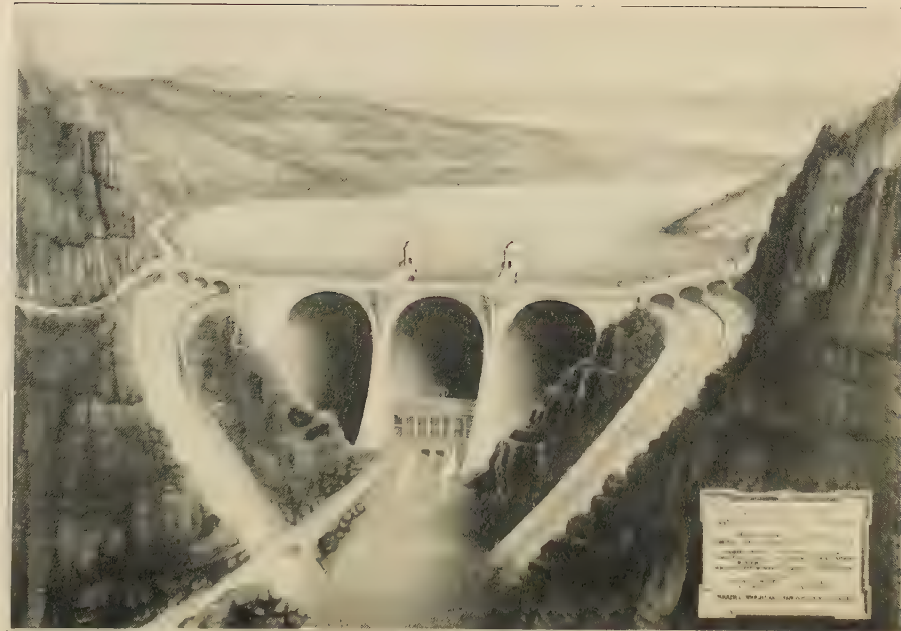
tennial was of one thousand horse power, the largest ever built up to that time, and just a little larger than industry demanded. Only a few years later came the next big step; for in 1882 Dr. Gustaf de Laval, a Swedish engineer, brought out the impulse steam turbine first proposed by Branca in 1628. These machines inaugurated the era of enormous amounts of power developed in one machine, and also the day of exceedingly efficient transformation of energy from coal to electricity. Units up to two hundred thousand horse power are being built today, and are delivering a kilowatt of power from a single pound of coal. Another recent development in steam power was the invention of the uniflow engine by Dr. Johann Stumpf of Berlin, by which device he increased the thermal efficiency of the medium-sized reciprocating steam engine for partial load as well as for full load. The uniflow engine is also taking its place as one of the most economical forms of steam engine.

Like the steam engine the present-day gas and oil engines are the results of many workers operating through a relatively long period of time. The first internal-combustion engine worthy of the name was built about 1675 and used gunpowder as fuel. The developments by Street, in 1794, and Lenoir, in 1860, bring us to the celebrated Otto engine, perfected at almost the same time as the Corliss engine, and exhibited at the Paris Exposition in 1878. The development of the internal-combustion engine for automobiles



GENERATING STATION OF THE BROOKLYN EDISON COMPANY

An example of the combined skill of structural, electrical, and mechanical engineers



COOLIDGE DAM, SAN CARLOS PROJECT, ARIZONA

The civil engineer has here combined beauty and utility

and airplanes has been of great economic significance. The development of the Diesel engine for marine propulsion played an important part in the World War and set the pace for the development of all forms of solid-fuel injection engines.

The invention and development of machine tools is one of the great contributions of the mechanical engineer. Precise work, as well as work on large pieces, was impossible until the engine lathe was devised. By it a competent workman could do more accurate work and at a greatly reduced cost. The metal-planer, the shaper, machines for cutting gear teeth, and then the turret lathe appeared, on which several operations can be performed without touching the part being machined. The automatic screw machine, grinding apparatus for precise finishing, and high-grade steel tools of a wide variety have been contributed by the mechanical engineer.

Through the development of mechanical power-generating and power-utilizing machinery, this profession has contributed a distinct part to the advancement of our modern civilization.

Mechanical refrigeration is not a new art. The practice of cooling bodies below the temperature of the surrounding atmosphere has been followed for ages, utilizing some method of evaporating a liquid in order to extract heat from the liquid itself. This found a practical application in 1755 in the construction of a vacuum machine freezing water by evaporation.

The vapor-compression machine of 1834 was the next step; but the first industrial application was Harrison's machine used in England in 1861. This was followed by the ammonia-compression machine built by Linde in 1873. Six years earlier the first absorption machine was in successful operation. Refrigerating machines are used today in more than two hundred important industries. We are told that more than $150,000,000 is now invested in household mechanical-electrical machines alone, and this industry is only in its infancy. The refrigerating machines in 1922 were capable of producing one million tons of ice. Today there are about a billion cubic feet of cold-storage space, in which much of the foodstuffs of the country is kept fit for human consumption. There is hardly a branch of engineering where the art of refrigeration does not directly apply, and many chemical processes rely upon it. The ice and the cold-storage plant involve the essential features of design found in the steam-power plant, and both types call for a thorough understanding of the laws of heat.

The field of heating and ventilation has grown into a great mechanical-engineering industry. Formerly people were satisfied with the crudest forms of heating appliances. From the early open-grate fire heating has been developed into a science which calls for a close study of the action of heat on the functioning of the human body, so that today air-conditioning in connection with heating and ventilation has be-

come a study of wide application to the industries. The insulation of houses is the first step toward a nation-wide effort to conserve heat and to keep the house comfortable in warm as well as in cold weather. One of the next steps is to apply refrigeration to the home, making it as comfortable during the summer months as it is kept during the other parts of the year.

The mechanical engineer has contributed in many ways to the art of transportation. One of the outstanding examples is the development of the modern locomotive, capable of hauling a load of twenty million pounds or more and operating with an economy comparable to that of a large power plant. The designing and building of freight and passenger cars, the development of the Diesel locomotive, the originating and perfecting of the air brake, the devising of mechanical features in signaling and automatic train control, and the improvement of railway-shop equipment are but a few of his many important contributions in this great field of public service.

Space limits a discussion of the development of the automobile and airplane, marine engines, and orehauling devices, and recent advances in the industrial application of compressed air, manufactured gas, powdered fuel, and automatic machinery, as well as progress in scores of other equally important branches of mechanical engineering.

A young man who carefully analyzes himself and decides that he is fitted for mechanical engineering

need have no fear of not finding an opportunity to be of service to the community if he will conscientiously dedicate himself, his education, and his training to the ideal of service.

A subcommittee of the American Society of Mechanical Engineers, at the December meeting, 1926, presented a report (see Proceedings, February, p. 147) which shows the value of a mechanical-engineering education to those whose positions were reported in the railway-transportation and railway-supply fields. This committee made a study of "the railroad careers of twenty-five railroad officers in six different grades."

AVERAGE AGES OF TWENTY-FIVE RAILROAD OFFICERS IN EACH GRADE SHOWING AVERAGE NUMBER OF YEARS REQUIRED TO REACH CERTAIN POSITIONS, AND TIME GAINED BY COLLEGE GRADUATES

	Age (Years)	Time in Railroad Service	College-Trained Men (Percentage)	Time for Non-College Man	Time for College Graduate	Time gained by College Graduate
President	58.3	30	53	34	24	10
Vice president	50.8	28.1	48	30.7	25.2	5.5
General manager	49	30.5	16.8	31.4	26.2	5.2
Superintendent of motive power	43.8	25.8	44	29.9	19.9	10
Mechanical engineer	35	13.75	80	14.6	13.5	1.1
Master mechanic	47.4	22.7	20	24.1	15.2	9.4

The right-hand column of the table shows the number of years gained by the college graduate in reaching each position listed, over the time required by the non-college man in reaching the same position. The officers, selected at random, are all employed by Class I railroads.

The superintendent of motive power is the active head of the mechanical department. A master mechanic is head of the repair shops of a division, and quite often has charge of both locomotive and car repairs. On most roads, however, the master mechanic has only locomotive maintenance to supervise. The mechanical engineer usually

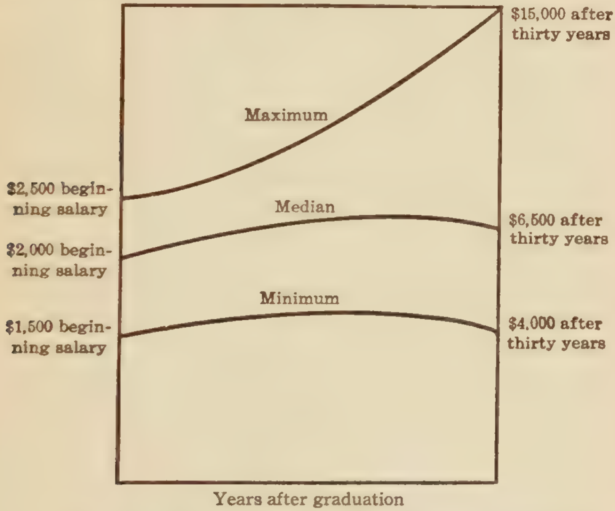


FIG. 14. Chart showing the earnings of mechanical engineers employed by railroads up to and including the position of chief of motive power

reports to the superintendent of motive power, and his work generally pertains to the design, alteration, and selection of rolling stock and shop equipment.

In each of the lines of activity mentioned in this chapter there are unlimited opportunities to design, build, operate, sell, finance, organize, investigate, and invent, according to the special ability of the worker.

The field, indeed, is large, calling for a diversity of talents and interests, and it liberally rewards the worker who can produce outstanding results. The mechanical engineer is not a stationary engineer; he does not drive a locomotive, or operate a lathe in

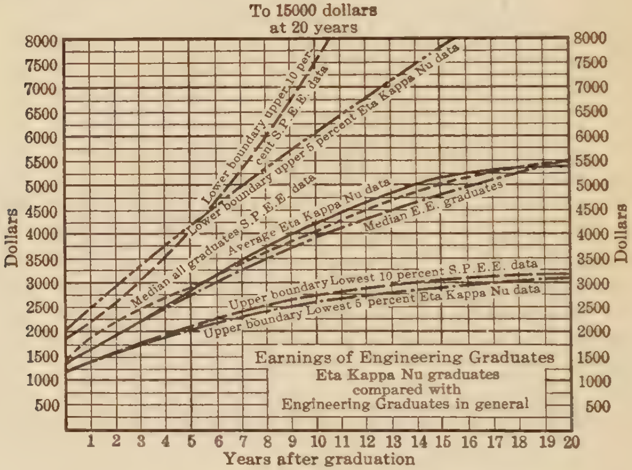


FIG. 15. Earnings of engineering graduates

Data assembled by Eta Kappa Nu and by the Society for the Promotion of Engineering Education

the machine shop. These are trades, and mechanical engineering is a profession. But the mechanical engineer must know these machines and others, because the world looks to him to keep improving them.

After a student has graduated in mechanical engineering, he is, as a rule, first given designing, or else he is assigned to the shops or power plants, in order to gain a knowledge of the products and proc-

esses of the particular industry. His work may be in erecting and testing new machinery or in the sales department. Of necessity his first work must be done under the supervision of an older and more experienced man, and consequently some of his real worth must be used to pay for this supervision. His earnings will not be large at this period. Later on, as he acquires familiarity with the products, processes, and policies of his company, he may win promotion to responsibility for design, for estimating or sales work, or for administrative duties.

In 1926 there were some ten thousand students in mechanical engineering in the schools of the United States, out of a total of some fifty thousand students in engineering of all kinds. While this seems like a large number, there are opportunities for all who show application and ability. More and more the industries of this country are putting trained engineers into responsible executive positions, such as that of president or of general manager; and the one reason why this has not happened before, and is not happening today to a greater extent, is because there have not been enough engineers with the necessary training, experience, and personal qualities for these jobs.

CHAPTER IX

INDUSTRIAL ENGINEERING

The well-trained industrial engineer, who is chiefly a mechanical engineer, is equipped to handle the engineering problems of industry peculiar to production design, production methods, equipment, operation, and the efficient coördination of these elements into an industrial organization through the proper administration of the personnel. He should be familiar with good business practice and accounting methods, as these are the criteria by which he judges the economy of his organization.

The various types. Among successful industrial engineers may be found the designer, or the inventive type; the analytical type, or the man who has ability to diagnose problems. The man who likes to make or build things is commonly classed as the constructive type of engineer. Industrial engineering attracts especially the operating, or management, type and the commercial, or sales, type — men who generally follow so-called application engineering. Lastly, perhaps, there is the research, or investigative, type.

These men find different interests in the natural divisions, or fields, of industrial engineering. These include factory planning and construction; industrial

accounting and cost work; production planning and control; the study of machines and wages; personnel administration; quality control and inspection; factory management and operation; manufacturing design and methods; and industrial finance and sales operations.

An industrial engineer is not necessarily a skilled mechanic, although the knowledge of a trade may be a distinct advantage to him. He is not trained to become a skilled machinist, carpenter, molder, core-maker, or the like, but rather is trained to handle problems of an engineering character incident to the economical production of goods. In other words, he has received a professional training which, with further practical experience, will enable him to handle the engineering and executive problems involved in the successful management and operation of factories, public utilities, and engineering concerns of similar character.

Factory planning. It would be well at this point to discuss more in detail the nature of his duties in the various fields listed. An industrial plant, no matter how complex, is, after all, a workshop used to produce a specified quantity of a product of a definite standard of quality at a minimum cost. The industrial engineer in the field of factory planning must solve problems in connection with the design, layout, and construction of various factory plants, including such items as choice of type of building; selection and installation of apparatus for the generation and

transmission of power; heating, ventilating, and lighting systems; and complete mechanical equipment for producing a given quantity of products. This involves, further, the selection and layout of machines and processes for the manufacture of the product — including the type and number of machines to be installed — and the arrangement of departments for economical manufacture.

Industrial costs. The industrial engineer specializing in industrial costs enters an attractive field offering unusual opportunities. His position is at the focal point of industry. The results of all the activities and operations of the business are shown in terms of dollars and cents on the records which he compiles and interprets. He maintains records of material in all stages of manufacture so that the money invested in these inventories may be kept at a minimum, at the same time avoiding the dangers of insufficient stocks. He compiles regular reports which bring the vital facts of the business to the attention of other executives. These reports point the way to more efficient management by fixing responsibility and furnishing an analytical statement of causes. He works out the distribution of expense on a scientific basis so that unit costs may be determined accurately. This accurate knowledge of costs is essential in order to plan and carry out an effective sales policy.

Production control. In the field of production control the industrial engineer has before him special

opportunities to advance to a controlling position in his organization. Production control is the directing of work and manufacturing processes in a factory. The engineer in charge of production plans the work in the shop. He gives starting dates for orders, determines sequence of orders and operations, decides which machines and equipment are to be used, and follows the progress of the work. He must know shop methods, processes, and capacity, as well as the fundamentals of costs; he must understand human nature, and be able to coöperate as well as to secure coöperation.

Time study. The industrial engineer specializing in time-study work is engaged in engineering research of the highest order. He studies the equipment and shop conditions which affect production. On the basis of this study, new equipment is selected or designed, and the shop methods for the handling of materials, the distribution of working space around machines, and the methods of holding work in jigs or fixtures are changed so that maximum production may be attained. In the same manner, he makes a study of the methods of doing the work itself — operations required, sequence of operations, and tooling — and improves these methods with a view to increased efficiency of operation. Another important phase of the time-study work is the accurate determination of the time in which a given piece of work should be done. This standard time forms, first, a basis of equitable wage payment, which contributes to the success of any manufacturing plant,

and, secondly, the basis on which the time required to do any job may be estimated and schedules prepared.

Personnel and inspection. The selection, placement, development, and retention of employees who are able to do work of the right quality and who have the right attitude toward management constitute, without doubt, one of the greatest problems in industry today. The solution of this problem is in the hands of the various divisions of the personnel department, and the industrial engineer who enters personnel work will find a new and very interesting field.

The field of quality control and inspection involves a knowledge of manufacturing processes, a thorough grasp of the principles of interchangeable manufacture, precise measurements, and a knowledge of the limitations of close tolerance for economical work.

Factory management. To the industrial engineer of proper qualifications (which are necessarily high) the field of operation and factory management offers exceptional opportunities and extremely interesting and satisfying work. He must have a personality which commands respect and loyalty, for he is primarily a handler of men. He must organize the forces under him so that each man is assigned to the work for which he is best fitted. He must correlate the work of those under him, prevent friction and ill-feeling from developing either between his men themselves or between the men and the management as a whole, and inspire those under him with a feeling of loyalty.

While it is not possible for him to know every detail of the work under him, he must have such a broad knowledge of that work that he can give prompt and correct decisions on questions referred to him for an answer. Upon him rests the responsibility for the smooth and efficient working of the whole industrial machine. Men entering this field usually come up through the manufacturing departments although some are chosen from service departments, — for example, the stores, material-handling, purchasing, and plant-maintenance departments.

Design and methods. Men entering the field of manufacturing design and methods have to handle such problems as the planning of complete special tool equipment to be used in the manufacturing of a given product. This includes the design of drill jigs, milling fixtures, gages, inspection fixtures, screw-machine tools; also cams, punches, and dies for press work and forging, and similar equipment. These engineers must also continue the design of the product after the functional design is complete, and must redesign it for economical manufacture. This involves the application of tolerance, clearance fits, and limits; the determination of locating points and registering surfaces; and the redesign of parts to facilitate set-up.

There is also a field for industrial engineers in the financial and commercial phases of industry, such as promotion, industrial-financing methods, advertising, and sales.

CHAPTER X

CHEMICAL ENGINEERING

"Chemical engineering is the art of manufacturing useful products through the application and control of chemical processes," so as to produce a uniform product of the desired quality at a minimum cost. The successful practice of chemical engineering depends on the proper "coördination of three essentials: first, knowledge of the pertinent sciences and the accumulated empirical data; secondly, skill and ingenuity in applying this knowledge to chemical enterprises; and thirdly, judgment in balancing values against costs."

As chemical engineering is one of the younger branches of the engineering profession, its history is rather brief. Just as the wheel and the lever were used long before the scientific principles of their operation were known, so did the quantity production of chemicals antedate any study of the principles upon which the art is based. The men who entered this field were "industrial chemists"; in general they knew a little less chemistry than a chemist, and less engineering than a mechanical engineer. The change from industrial chemists to chemical engineers occurred when it was seen that a large number of

operations, developed supposedly for a particular industry, were duplicated in many other industries. The quantitative study of these so-called "unit operations" — heat exchange, filtration, distillation, drying, etc. — constitutes chemical engineering as it is today. The result has been the development of men who could *design* apparatus rather than merely build it, thus avoiding much large-scale experimentation and the accompanying expensive changes in construction necessary to get efficient operation.

The advantages of this classification of chemical industry over that previously used — rubber, soap, textiles, petroleum, etc. — are manifold; but one of the most important to the prospective student is that specialization on one or more unit processes does not limit him to any one branch of industry, whereas specialization on any one material confines him to that group. He therefore does not have to decide on the particular field he wishes to enter before he is properly qualified to do so.

Students who intend to take up this work need thorough training in the three fundamental branches of science: chemistry, physics, and mathematics. These are of about equal importance. It usually takes three years to obtain a good working knowledge of these subjects. During this period the fundamental phases of mechanical and electrical engineering should be studied, so as to obtain an understanding of their relation to chemical engineering.

The student is then ready to proceed with the quantitative study of the unit operations. These operations may be divided into two classes: (1) primary, consisting of the flow of heat and the flow of fluids; and (2) secondary, consisting of distillation, filtration, separation, evaporation, absorption, and others of a similar nature, for which a knowledge of the primary operations is essential. It is very advisable to carry the training further by means of graduate study and research, and some schools offer the opportunity for research in the plant.

When the young engineer goes out on his first job, he may be assigned either to the laboratory or to the plant. He may choose any chemical industry, and his training fits him equally well for all of them. Many large corporations have development and research departments, in which all classes of work, from laboratory scale to factory scale, are carried out. The young engineer takes part in tests on equipment already in use, and works on the design of new equipment. Frequently, if he has handled his work satisfactorily, he follows the process through the plant, and then either becomes factory superintendent or else returns to the laboratory to handle a new problem, depending on the character of the work for which he is best suited. In general, his main function is to fill the gap between the laboratory chemist and the plant operator.

After he has obtained sufficient experience in the plant to become acquainted with its problems and

methods, he finds the way open to an executive position, such as that of plant manager or technical director. As in any other branch of engineering, personality, initiative, and the ability to carry work through to a successful conclusion are the qualifications which bring success in chemical engineering.

Health and Recreation

1. Have you good health?
2. What games do you like?
3. What books do you like best?

Ambition

1. What kind of work do you believe you would like to do?
2. Why?
3. Are you a leader?
4. Are you good at teamwork?
5. Are you self-reliant or do you prefer to depend on someone else?
6. Check the occupation which you would like to follow:

Surveyor	Mechanical engineer
Electrician	Draftsman
Stationary engineer	Auto mechanic
Architect	Building and constructing engineer
Civil engineer	Industrial engineer
Electrical engineer	

7. What is your idea of the work which you would do in the field which you checked?
8. Why did you select it?

CHAPTER XI

MINING AND METALLURGICAL ENGINEERING

A civilization may be measured by the quantity of metals and mineral products produced and consumed. Thus mining is mentioned in the oldest records of mankind, and has continued and expanded with the development of our modern industrial civilization.

The romance of gold and silver mines led the Spanish explorers into South America, the Americans into California, and the English into South Africa and Australia. Of greater value has been the production from nature's storehouses of copper in Montana, Michigan, and South America; from the iron mines in Minnesota, New York, and Cuba; and indeed from the deposits of the many other metal and mineral products, ranging from asbestos to zinc.

The working of these mines and the search for new ones must be ever on an increasing scale and at increasing depths. Thus mining requires not only a knowledge of nature's laws but heavy hoisting machinery and proper ventilating and pumping equipment.

Woodrow Wilson said, "The work of the world waits on the coal miner; if he slacks or fails, armies and statesmen are helpless." He recognized coal as being the source of power that runs our railroads, drives our

machinery, melts our iron, and heats our homes. Today the United States produces annually five hundred and fifty million tons of soft coal and one hundred million tons of hard coal. This is about half the production of the entire world. If this were all put in coal cars on a railroad, the train would reach approximately five times around the earth at the equator. As the mines grow larger and deeper, engineers are increasingly needed to design and supervise the machinery and the workings and to systematize and plan production. Within a few years most of the coal will be produced by machinery.

The production of petroleum or oil is also in the general province of the mining engineer or petroleum technologist. Out of this crude petroleum we get gasoline, fuel and lubricating oil, and many other products. The mining geologist who studies the rocks to determine where the oil wells should be located is succeeded by the petroleum technologist when wells are drilled and the field is brought under production. The petroleum business has expanded greatly within the past few years, and more and more trained men are being employed to increase the production, save the supply remaining in the ground, and devise new and better methods of recovery.

After the geologist and the mining engineer have discovered and produced the minerals, the metallurgist must refine them into a condition where they are usable. Thus iron ore must be melted in the furnace into pig

iron and later refined into various kinds of steel. In general all metallic minerals produced go through similar refining processes. Within the last few years the increased use of alloys, or the combination of two or more metals to form a new metal, has greatly increased the field of work of the metallurgist.

Certain minerals, such as clay or limestone, do not yield metals. These minerals we manufacture directly into brick, tile, pottery, porcelain, glass, cement, and other necessities. For this field of work in the mineral industries the clay-working, or ceramic, engineer is needed.

Mining engineering includes the science and art of locating ores and other mineral products and extracting them from the earth. It includes the geology, mineralogy, and chemistry of ores, petroleum, ceramic products, and coal and coke. The processes of preparing the product for and transporting it to the market are also included.

Metallurgy is the science and art of extracting (or smelting), producing, testing, refining, and using metallic products and alloys. Heat treatment and the selection of steels and alloys for special purposes are important features of metallurgy. Ceramics concerns itself with the occurrence and manufacture of cements, refractory materials, and clay products in general.

Besides the usual foundation of mathematics, chemistry, physics, English, and drawing, students in mining pursue courses in geology, mineralogy, mechanics,

and subjects in metallurgy which are related to their mining work. Mine structures, equipment, ventilating, and mining methods are taught in the last year. At this time it is usual to make inspection trips to mines and to do field work in geology.

Mining graduates enter the operating corps of various mining companies and fit themselves for operating or executive positions; or they are attached to the engineering staffs and employed on design, installation, or maintenance of surface and underground plants. Others enter the sales field for companies making or handling mining appliances. The United States Bureau of Mines and other investigative agencies offer opportunities for men interested in research.

The prospective metallurgical engineer pursues advanced courses in by-product coking processes, iron and steel metallurgy, the qualities of special alloys, heat treatment, temperature control, plant equipment and operation, and the treatment of nonferrous metals. Graduates enter the various plants for the treatment of ferrous or nonferrous ores and metals and engage in plant operation or in the control of materials and processes. Some design metallurgical plants; others enter sales, teaching, or investigative work.

CHAPTER XII

OTHER ENGINEERING COURSES

During the last decade a number of optional courses or curricula have been adopted and offered by various institutions but have not yet been generally accepted. Some of them will probably demonstrate their permanent value.

Administrative engineering, general engineering, and engineering administration. These are titles given to various curricula which include a survey of engineering subjects, studies in the field of business and finance, and general subjects. Their purpose is to prepare graduates to enter business and industry where engineering principles are used by those in managerial or executive positions.

Aëronautical engineering. This includes the design, construction, and operation of airplanes, hydroplanes, dirigibles and other balloons, and their equipment. A few colleges give instruction in this field.

Automotive engineering. The term "automotive engineering" is applied to a branch of mechanical engineering which has grown in importance and rapidity so that it is recognized as a definite field. It includes the design, construction, and operation of automobiles, trucks, busses, and tractors. The

research, advancement, and improvement in economy, durability, and reliability of highway transportation have been due largely to automotive engineers.

Bridge engineering. The graduate in civil or structural engineering who desires to become a bridge engineer usually enters the drafting office of one of the large steel-fabricating companies or the employ of a firm specializing in bridge engineering.

Ceramic engineering. This includes the study of the usual fundamental subjects of mathematics, chemistry, and physics, together with geology, mineralogy, and the study of all forms of clay and shale products. It is intended to prepare young men to enter industries making brick of all kinds, cement, terracotta tile, and other clay products. Refractory materials, or those which resist high temperatures in furnaces of all kinds, receive particular attention.

Electrochemical engineering. The electrochemical engineer deals chiefly with the application of electricity in the chemical and metallurgical industries. At present the most important phases of this branch of engineering relate to the refining of metals by electrolytic and electric-furnace processes, electroplating, chemical analysis by electrolysis, the electrolytic production of chemicals, the alloying of metals, the production of such materials as carborundum and aluminum in electric furnaces, the application of the electric furnace in the iron-and-steel industry, and the development and manufacture of electric batteries.

Certain activities of the electrochemical engineer are similar, in a general way, to those of the electrical engineer. He deals with the design, development, manufacture, and sale of electric batteries, and with the equipment necessary in the application of electrolytic and electric-furnace processes in the industries; he installs this equipment and, by preliminary tests, determines the conditions under which it will give the most satisfactory operation; he supervises the operation of the apparatus, and conducts tests necessary to insure the production of satisfactory products.

Many electrochemical engineers are engaged in other than the chemical and metallurgical industries, in industrial research carried on for purposes of developing new or improved materials which may aid in the solution of problems peculiar to those industries, or of developing methods whereby electrochemical processes may be substituted for less desirable processes. Other electrochemical engineers are engaged in investigating the economic aspects of the utilization of existing sources of electric power in electrochemical processes, or in determining the electrochemical applications which might be made possible by the development of new sources in electric power.

Marine engineering. This includes the design, construction, and operation of all kinds of steam, electric, and oil power for the propulsion of ships and their necessary auxiliary equipment.

The curriculum includes mathematics, science, mechanics, thermodynamics (or the theory of heat), the design of marine machinery, and related subjects in electrical engineering.

Very considerable advances have taken place in marine propulsion in recent years due to the use of oil-burning equipment, oil engines, and steam-electric or oil-electric power plants.

Naval architecture. This includes the design, construction, and equipment of ships of all kinds. The naval architect has investigated the resistance of different types of hulls and the advantages of various models. The design of yachts, freight and passenger vessels, and cruisers, battleships, submarines, and other types of warship is the province of the naval architect. The equipment of the modern ship is exceedingly complex, as it has all the features of a floating city. The limitations of space require ingenuity and skill in providing for economy of operation, speed, reliability, and safety.

Railway electrical engineering. This branch of engineering involves the applications of electric power to transportation. It includes the equipment and operation of electric street railways and interurban railways, but is concerned more especially with the problems of electrification of steam railroads, tunnels, and terminals. It includes also electric switch and signal apparatus, as well as the newer safety devices, such as remote control.

Railway mechanical engineering. This includes the design of railway cars, locomotives, and shops, and the supervision of operation of steam-railway motive power and of roundhouses and similar equipment. The manufacturers of locomotives and other railway equipment employ men trained or experienced in the field of motive power.

CHAPTER XIII

TEACHING AND RESEARCH

Teaching. The best teacher is one who leads students to develop their analytical powers, their judgment, and their ability to obtain and to apply knowledge. There is always an opportunity for the young man who can inspire students to want to know both by his own example and by his methods of instruction. The teacher should have a deep interest in his subject, and should be well prepared in its fundamentals and in those methods of presenting basic principles on which good teaching is founded.

The teacher of engineering subjects should be interested in the most recent developments of the art and the science. He should question the truth of a new proposal or principle and should have an interest in the investigation and testing of new products, apparatus, and processes.

The quantity of information which a young teacher may have is not so important as his knowledge of how to use that which he has. The graduate of an engineering curriculum who expects to teach should have additional courses of instruction in *how* to teach. If he has the analytical type of mind, and if he is interested in students, their personal problems and their

development, he has some of the qualifications of a good teacher. In addition, he should be skillful in speaking and writing the English language, and he should know at least one foreign language, in order that he may understand important contributions in the leading foreign journals.

A good teacher is of the cultured type, which means that he is interested in some other fields of knowledge besides the one in which he has majored. The highly specialized teacher, with no breadth of interests, may impress students by his narrow and deep knowledge, but he will not inspire them in the more important subject of living.

The student who has natural ability and a strong desire to teach will find an opportunity. The salary is not yet as large as that which men of equal capacity will earn in industry; but the graduate in engineering who teaches, and who then embraces opportunities to improve his knowledge of the art by a few years of experience and, after that, by summer work, will find a fair return, in proportion to his ability, energy, and personality.

The engineering teacher of experience and exceptional ability will find special opportunities for public service and for advising corporations. The teacher has time for study, for travel in order to observe engineering progress, and for practice.

Research. The research type of engineer is interested in investigation and invention. He may be

concerned principally with finding new laws which control natural phenomena and not be interested in the practical applications of what has been discovered.

He may be interested in finding causes in order that apparatus may be perfected, and he may perfect it. He may be of the development or application type, seeking for a way to apply a theory discovered by someone else, and perhaps making a practical application through the invention of new apparatus. He may be ingenious in making the form attractive and may change the form in order to economize in cost of manufacture.

These various types, from the pure-research to the application type, are necessary to industry and to the numerous public and private laboratories devoted to investigation, invention, and development.

Several large corporations have staffs of research physicists, chemists, and engineers, and expend on development large sums of money (in one instance reaching five million dollars per year).

The following extract is from an article entitled "Engineering Research as a Career," which Dean A. A. Potter of Purdue University prepared for the National Research Council:

Opportunities for research engineers. The research engineer has an opportunity to aid in laying the foundation for future industrial and engineering progress. He may succeed in adding to human comfort and in making history. A research career offers an opportunity for

doing constructive and enduring work which is of vital importance to society.

The true research man is constantly growing, and has the intellectual gratification and inspiration which comes only to those who create, who achieve, and who add to knowledge. His mentality is stimulated by constant association with the best products of human thought.

The field of engineering research is very broad and no opportunities are lacking for those who have the proper qualifications and training for a research career. Directors of research in industry, in Government laboratories, and in universities claim that the United States of America has too few men who have the training, the ability, or the desire to carry on investigations and to make new discoveries through research.

The research engineer can utilize his talents in various ways:

Skilled investigators are needed to man the laboratories of industry. The most prominent manufacturing industries of this country are maintaining research laboratories of great expense. The large electric utilities are maintaining research departments to lower the cost of generating power. The railroads of the country are also interested in research and in some cases have developed test departments which carry on considerable research.

Several of the United States Government departments and bureaus are constantly carrying on engineering investigations. The most prominent of these are the Bureau of Standards at Washington and Pittsburgh, the Bureau of Mines at Pittsburgh, the Bureau of Public Roads at Washington and other places, the Forest Products

Laboratory at Madison, Wisconsin, the Watertown Arsenal, and the United States Naval Experiment Station.

In several states engineering investigations are being carried on by certain bureaus and departments of the state government.

There are also many private engineering laboratories which are devoted to investigations of materials and processes for commercial purposes. Several institutions are carrying on coöperative research with industry. The Mellon Institute of Pittsburgh and the laboratories of the Factory Mutual Fire Insurance Company are examples of such research activities.

While the research laboratories of the industries, the Government, and the private research institutions offer much opportunity for engineering research, the universities and colleges are the most important agencies for creating new engineering knowledge as they are the fostering places for pure scientific research. The accumulation of knowledge for the benefit of humanity has always been recognized as one of the most important functions of a university. As compared with the industrial or private laboratory the research laboratory of an educational institution has greater freedom from interruptions, an atmosphere which is scholarly and sympathetic to research, and no necessity to safeguard results by secrecy. To advance engineering research more than twenty engineering colleges have established engineering experiment stations where men are employed on whole or part time to carry on investigations.

Qualifications for the career of research engineer. Great research men possess a spirit of adventure, imagination, ingenuity, clear vision, persistence, absolute integrity of

purpose, good training, and a spirit of unselfish service for the benefit of humanity. A person to be most successful as a research engineer must be interested in creating new things, in discovering new laws, in perfecting new processes, in solving new problems, and in extending the boundaries of human knowledge. Coöperative ability is very valuable for a research man. No person should take up research as a career if his aim in life is to make money. Good research men are well paid, but they find their greatest reward in their love of the work. Their inspiration comes not from monetary returns but from a desire for achievement.

Research calls for men of superior mentality who are highly trained. A person who is not studious should not undertake research as a life work.

Preparation for a research career in engineering. Engineering research is based upon physics, chemistry, and mathematics. The more thorough the preparation in these subjects the greater are the chances for success. The greatest contributions to engineering progress can best be made by a person who has not only engineering knowledge, but also a broad and thorough training in the sciences which are basic to engineering. The power of clear English expression of the mathematical, physical, chemical, and engineering relations is an important part of the equipment for the research engineer.

To best prepare for a research career in engineering, the undergraduate student should give special attention to courses in mathematics, physics, chemistry, mechanics, and other theoretical subjects. If possible he should pursue advanced courses in mathematics during his junior and senior years. The completion of the undergraduate

course should be followed by several years of graduate study. It is often advantageous for a person to devote a year or two in practice before taking up prolonged graduate study. In most cases, however, one will do best to take one year of graduate work immediately after graduation. This is particularly advisable in the case of those who have had contact with industry before graduation from college. A person interested in research will make a mistake if he remains too long in industry before undertaking graduate work.

Practically every engineering college of standing offers courses leading to the Master of Science degree in engineering, and several institutions are offering graduate courses leading to higher degrees, such as Doctor of Engineering, Doctor of Philosophy, or Doctor of Science. The number of such institutions is certain to increase, as the value of graduate study is becoming more appreciated by engineering students.

A person interested in making research engineering his career will have no difficulty in securing means which will enable him to prepare himself properly by graduate study. Educational institutions are constantly looking for outstanding men to be appointed to research or teaching fellowships, or to assistantships. The engineering experiment stations offer particularly good opportunities for those who are interested in research. Appointment to a part-time teaching or research position gives one the opportunity to pursue graduate work at little expense.

Engineering research as a career should prove most attractive to any man who has the personal qualifications and the courage to prepare himself thoroughly for his life work.

CHAPTER XIV

THE ÆSTHETIC, CULTURAL, AND ROMANTIC IN ENGINEERING

Engineering is considered to be preëminently practical, and very few of those who profit by the works of the engineer think of the æsthetic, cultural, and romantic phases which are interwoven with the practical.

Architecture is one of the fine arts, and therefore the æsthetic, or artistic, is a primary factor. The beauty of public and private buildings is the product of the architect's mind. Cathedrals, and national, state, and city buildings and monuments, embody his tastes. The tall office building has led to the creation of a new architectural note of a distinctly American character. The æsthetic dominates the creations of the architect.

The architectural and the civil engineer consider also artistic style in their designs. Many of the early timber and iron bridges were more utilitarian than artistic; but as the country grew in wealth more æsthetic character was given them, and today both materials and design are chosen with a view to producing a pleasing effect on the eye. Europe has many fine examples of bridges which are monuments of æsthetic

design. Such are the bridges over the Rhine, the Seine, the Rhone, and other rivers. In the United States the gracefulness of the Hell Gate arch bridge, the High Bridge over the Harlem, and the Niagara and St. Louis arch bridges appeals to all observers. The suspension bridges at Cincinnati, New York, Philadelphia, and Niagara are monumental in size, but serviceability and beauty are interwoven. Many large and small concrete arch bridges give the effect of combined grace and strength.

Similarly, a pleasing effect is sought today in designing power houses, hydroelectric plants, dams, reservoirs, and other structures. Under the combined influence of the architect and the engineer, factory buildings have also changed. The tendency is toward structures which are durable, fireproof, and well lighted and which make a distinct appeal in line and color. Many of the larger corporations have not only built superior structures, but have laid out parks and model cities, with their various utilities housed in buildings of pleasing design and homogeneous in type.

Machines, engines, and other apparatus are given a finish and even a profile which are more attractive while at the same time serving their purpose just as well. The automobile is a good example of this: its evolution has been from the buggy with an engine in it to a distinctive artistic vehicle in which harmony of color, lines, and proportions is emphasized.

The selling value of good appearance is appreciated in small motors, large steam engines, water tanks and towers, bridges and buildings. As the æsthetic is being emphasized more and more, the engineer with an appreciation of the beautiful is a greater asset to his community, and the value of his services is being increasingly recognized.

"Culture" may be defined as the training, disciplining, or refining of the moral and the intellectual nature — refinement in manner and taste. In the Middle Ages Greek and Roman literature was the finest source of philosophy, logic, religion, and history. Education was limited to those preparing for the priesthood and the law. Slowly medicine and alchemy grew, and chemistry unfolded its wealth of knowledge. A body of facts and principles called science was developed, but the old tradition persisted that culture was the product of Greek and Roman literature, philosophy, and history. There are many who still believe that culture is buried with the dead languages.

The humanities included the fundamentals of mental and moral refinement and discipline. New humanities have been born, and psychology cannot be denied its place therein. Biology is one of the humanities. Both subjects are useful, but they are none the less cultural because useful. There is no finer mental discipline than that offered by modern mathematics. Geology and astronomy give glimpses into the history

of the earth going back millions of years. Astronomy points out how law controls through a space as nearly infinite in its dimensions as anything which we can conceive.

The fact that these subjects, along with physics and chemistry, form the foundation of modern industrial development makes them no less cultural because they are useful and practical. The bed-rock of engineering education is cultural. Mathematics is an exact science in which logic is the dominant factor and honesty is insistent. Physics teaches the laws of gravitation, force, heat, light, sound, and electricity. These subjects form a considerable part of our literature. Finding the depth of the ocean by sound waves, the recent measurements of the velocity of light, the use of light in treating disease and plant growth, the heat of the sun, sun spots, and radio reception are common topics.

In this dynamic age a course in electricity becomes almost a necessity; without it one is hopelessly ignorant of the most marvelous developments of human knowledge of the last decade. Thus, sound is transformed into Hertzian waves, and these waves, in turn, produce sound. These principles, embodied in electric apparatus of extreme delicacy, permit men to talk across the Atlantic Ocean. By radio the position of fog-bound ships is communicated to them from shore. The S O S call for help has saved thousands of lives endangered by marine accidents. With the aid of

electric waves measurements of objects can be made to the hundred millionth of an inch. These are imposing extensions of our understanding of natural phenomena.

Culture depends less on the subject than on the attitude of mind of the student and of the teacher. If the applications of physics, mechanics, heat, and electricity are the only goal, then no subject is as broadly cultural as it will be if the social and economic aspects of the subject are also emphasized. Railway, water, and highway transportation has changed and is still changing our social and political conditions. Water power and steam power have lightened the manual labor of millions, and will multiply their contribution to human welfare in the next decade or two.

These are aspects of engineering which are too often overlooked by the young man who is selecting his life work. Engineering must be regarded as inspirational, reverent, and appealing by those who desire to add something to the sum of human comfort and progress.

Furthermore, the engineer needs to know something of the arts and sciences which he does not employ in his daily work. If he knows only engineering, he is not cultured in a large sense. While he may not hope to know much of our infinitely complex civilization, he should cultivate some one field, such as flowers, music, art, literature, or history, as a recreation, — a variant from the consuming habit of thinking continuously about one subject.

The student whose time is well organized can carry an engineering course — generally agreed to be one of the severest — and still have time for a diversion which is at once cultural, broadening, and recreative. To postpone it until after student days are over is to postpone it to the hereafter in most instances; for the engineer who succeeds must remain a student, and his days will be full.

Romance is defined in Webster's International Dictionary as "any fictitious and wonderful tale; now, especially, a sort of novel, whose interest lies not so much in the depiction or analysis of real life or character as in adventure, surprising incident, or the like." Just as truth is stranger than fiction, so the experiences of engineers, although rarely seen in print, frequently offer excellent material for tales of high adventure.

F. Hopkinson Smith, the author of "Caleb West, Master Diver" (which is in its essentials the story of the construction of Race Rock Lighthouse), was a courageous engineer and a pioneer builder of lighthouses on our shores, as well as an artist of unusual talent and a man of vigorous personality and the highest character. He rose from the shop to a clerkship, but resigned because his employer was unjust to a contractor. He then became a contractor himself and built a railroad on Long Island, the sea wall around Governor's Island, and the foundation and pedestal for Bartholdi's "Statue of Liberty." He next undertook to build Race Rock Light. In an article written

just after the death of Mr. Smith, Thomas Nelson Page says:

It is twenty-odd years since I heard from him the story of that early venture, but it is still fresh with me. And it stands today in my memory as a triumph of courage, resourcefulness, and common sense over discouragement and disaster in many forms. Frank Smith always gave the credit for his final success to his Yankee skipper, Captain Tom Scott — whom he has celebrated in "Captain Joe," and in "Caleb West, Master Diver." No better description of the Yankee skipper, tough, sturdy, tender-eyed, and fearless, exists in literature than Hopkinson Smith has given in this portrait of Captain Tom Scott.[1]

Mr. Page then goes on with the following story of the building of this lighthouse off New London Harbor, miles from shore, in Long Island Sound.

First, the foundation of huge stone blocks which he put in would not hold on the slanting rock, and they had to be taken out. And here his versatility and genius came into play. I recall his description of the way he fell on the expedient of Portland cement, and how he went and on an open common chose a bit as nearly like the submerged rock as possible and experimented until he was satisfied. He then went back to the rock and laid down his cement, and when this was done he had a level and substantial base for his stone superstructure. He had hardly got over this difficulty when his stone barge, the *Dolly Varden*, blew up — and with it went all he had in the world

[1] From "Frank Hopkinson Smith," by Thomas Nelson Page, in *Scribner's Magazine*, September, 1915. Used by permission of Charles Scribner's Sons, publishers.

and, for the moment, all his hopes. Summoned by a telegram he went to New London. Captain Scott was at the wheel when the *Dolly Varden* blew up, and, as he rightly said, when he saw "the deck a liftin' he cal'lated it was no place for him," and dived overboard. He met Smith at the train and asked him quietly: "We-all, Mr. Smith, what are we goin' to do now?" Hopkinson Smith used to say it was the look in Captain Scott's eyes when he met him that day that decided his career. He saw in the old skipper's eye the look that has made the American people and recognized that he was simply waiting for him to give the word. So he said: "We are going to build the Race Rock Lighthouse, Captain."

"All right, Sir," said the captain, and the rest was mere detail. When it was finished Race Rock was ready to stand the fury of every storm, and its contractor was equally prepared to meet the buffets of the heaviest seas.

Robert Louis Stevenson tells of the many daring feats, narrow escapes, and thrilling adventures of his grandfather and father in building beacons and lighthouses on the shores of Great Britain at a time when pirates, wreckers, and smugglers viewed their works with disfavor. Stevenson gives a picture of the engineer of a hundred years ago in a few words which are worth repeating:

The rains, the winds and the waves, the complexity and the fitfulness of nature, are always before him. He has to deal with the unpredictable, with those forces (in Smeaton's phrase) that "are subject to no calculation"; and still he must predict, still calculate, at his peril. His

work is not yet in being, and he must foresee its influence; how it shall deflect the tide, exaggerate the waves, dam back the rain-water, or attract the thunder-bolt. He visits a piece of sea-board; and from the inclination and soil of the beach, from the weeds and shell-fish, from the configuration of the coast and the depth of soundings outside, he must induce what magnitude of waves is to be looked for. He visits a river, its summer water babbling on shallows; and he must not only read, in a thousand indications, the measure of winter freshets, but he must be able to predict the violence of occasional great floods. Nay, more; he must not only consider that which is, but that which may be.[1]

Sir Benjamin Baker was the first engineer to build a large cantilever bridge. When he proposed to construct the Forth Bridge, Scotland, on this principle and to give it a span of 1710 feet, the board of directors objected that there was no precedent and that it was impossible. Baker then constructed a miniature bridge of the same proportions and demonstrated to the board how it carried the load. The evidence of their eyes was more convincing than columns of figures; as a result, Baker was permitted to design a bridge which for the next thirty years had the longest span of any bridge in the world. From this we see that the engineer must frequently resort to perspective drawings or water colors to give business men a clearer idea of what is proposed.

[1] From "Records of a Family of Engineers," in "Letters and Miscellanies of Robert Louis Stevenson." Used by permission of Charles Scribner's Sons, publishers.

The history of the early highway, canal, and railroad builders is the story of pioneer adventure. Danger from hostile Indians, from floods, and from blizzards required a physical hardiness seconded by courage, resourcefulness in emergency, ability as a leader and organizer, and a love of life.

There is romance and high adventure in the life of the engineers who enable us to pierce the darkness with electric lights, to explore the human body with X rays, to navigate on or beneath the surface of the oceans with the gyroscopic compass, to travel in the air, as well as by land and water, at tremendous speed, and to communicate across the seas by cable and by wireless; and who by their skill protect the life, health, and safety of millions who dwell in great cities, — cities themselves made possible by the work of engineers.

APPENDIX

Leonardo da Vinci (1452–1519)

As we read Giorgio Vasari's life of Leonardo da Vinci we are impressed with the versatility of Da Vinci's talent. As the biographer tells us, he was the "most universal genius of the Renaissance." Painting, sculpture, music, philosophy, botany, geology, all in turn received his attention; no less did mathematics, architecture, and engineering. Thus he is recognized not only as one of the greatest artists of all time, but as the link between the ancient Greek mathematicians and the scientists and engineers of today.

The first thirty years of Da Vinci's life were spent in Florence, Italy. As his talent for designing and painting showed itself very early, his father sent the boy to study with Verrocchio, the foremost Florentine artist of the day. There he very soon showed the genius that later gave to the world such masterpieces as "The Last Supper" and "Mona Lisa."

Perhaps it is to what in a lesser man might have been regarded as a weakness that we owe our opportunity to classify Da Vinci as an engineer. He had a great and never-satisfied curiosity. This caused him many times to abandon work before its completion. Fortunately, however, it caused him also to turn to all new enterprises. Thus we find him seeking the society of men of science and making his own experiments and investigations.

Often he made designs for buildings merely to satisfy his desire to work out the architectural problem. An example of this, probably, is the model for a cupola for Milan Cathedral. He submitted his designs to the building commissioners in 1487, but took them back with a promise to make others. This apparently was never done, and the cupola was finally designed by other artists. Meanwhile Da Vinci, who was now living in Milan under the patronage of its duke, continued his designs for buildings presenting every possible difficulty of construction. He drew plans, also, for mills, guns, and war machinery.

Of greater practical value, however, were his canal constructions. By means of a series of canals the river Adda was made navigable up to Lake Como. On the estates of the duke of Milan he constructed an irrigation canal in which, by means of "one hundred and thirty steps a quarter of a yard high and half a yard broad," he diverted a violent river and transformed a useless swamp into fertile meadows.

The great plague which swept over Milan in 1485 and 1486 caused Da Vinci to plan a new city on much more hygienic lines. In fact, in his ambitious plans he proposed that the duke of Milan should build ten new cities in which light, air, and cleanliness should prevail. The cities were to be located on rivers regulated by locks, and wide streets and spacious squares were to be provided. One suggestion is especially modern: his design calls for streets on two different levels, the upper for foot travel, the lower for vehicles. Underneath all the streets were canals to be traversed by gondolas. Here, indeed, we feel that Da Vinci almost joins hands with the engineers who are studying the traffic problems of the present day.

In spite of the modern suggestion just given, however, we must not forget that Da Vinci lived at a time when war was still the pastime of dukes. And so in a lengthy letter to his patron we find him emphasizing his skill as a military engineer. "I have," he says, "a method of constructing very light and portable bridges, to be used in the pursuit of, or the retreat from, the enemy, . . . proof against fire or force, and easy to fix or remove. . . . I have means whereby any fortress may be destroyed, provided it be not founded on stone. . . . I have also most convenient bombs, proper for throwing showers of small missiles, and with the smoke thereof causing great terror to the enemy." And so he continues to enumerate in great detail every kind of device for waging war on land or sea. Perhaps fearful that he may appear too boastful of his power, he closes with the offer: "And if any of the above-named things shall seem to any man to be impossible and impracticable, I am perfectly ready to make trial of them in whatever place you shall be pleased to command."

We thus see in the life of this man who died four centuries ago the unusually even balancing of those qualities which every successful engineer should have: love of beauty, imaginative power, and trained mechanical skill.

James Watt (1736–1819)

Occasionally it happens that an anecdote is so often told concerning a man that the mere mention of his name recalls the anecdote. Thus, we have been told the story of James Watt and his mother's teakettle and have been assured that it was the lifting and lowering of the lid, as the water boiled, that led Watt to his conclusions regard-

ing the power of steam. Whether the story is true or not, Watt's name has been so associated with steam power that many other achievements of his have been overlooked. He could make an organ as well as a steam engine; he was the inventor of a device for recording the weather changes; he set up a very successful copying press; and he made several useful chemical deductions, one of which was that water is composed of two elements. He was also a surveyor of ability, who did much to improve the harbor and the water system of his native town of Greenock, Scotland.

James Watt was the son of a maker of mathematical instruments, and the boy gained his first knowledge of this work in his father's shop. Later, he was apprenticed to other instrument-makers in Glasgow and London. To the London shop came many of the prominent scientists of that day, and young Watt listened attentively to their discussions. In this way he became familiar with the inventions of Savary, Newcomen, and others and with the theory of latent heat just then propounded at Glasgow University.

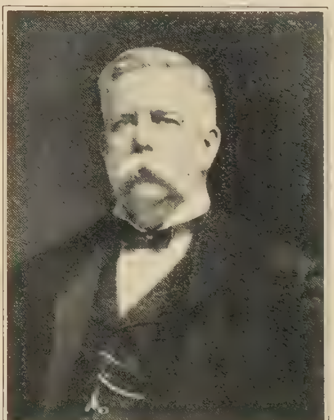
On the completion of his apprenticeship he settled in Glasgow as instrument-maker to the university. His workshop was within the college grounds and soon became the gathering place for all who were interested in the new scientific developments.

As often happens, Watt made his greatest contribution to science in the course of what at first appeared merely routine work. A Newcomen steam engine belonging to the university was brought to him to be repaired. Watt's interest was aroused, because for some time he had been experimenting with steam to propel vehicles, so far without

JAMES WATT

DR. C. P. STEINMETZ

JOHN ERICSSON



GEORGE WESTINGHOUSE

SAMUEL REA

success. Studying the Newcomen steam engine, he saw the solution of his own difficulty and at the same time the way to improve upon Newcomen's invention. The Newcomen type was an extravagant consumer of steam because the water, injected directly into the cylinder to condense the steam, cooled the cylinder, which must then be reheated before more power could be generated. Watt's great invention was a separate condenser by means of which he was able to obtain a high and uniform temperature in the cylinder.

But success did not come all at once. Although he saw what was needed, the lack of proper tools, especially those with which to make perfectly fitting cylinders and pistons, caused repeated failures. It was after such a failure that he turned his attention to other things, to earn enough money to support his family. Then, as soon as he had leisure time and something saved, he turned back to the engine.

After some years he formed a partnership with Matthew Boulton, an English manufacturer. Finally their opportunity came. Mines in Cornwall had been abandoned because there was no engine of sufficient power to pump and keep them dry. Watt demonstrated the capacity and economy of his engine, with its separate condenser. It proved its value, the mines were reopened, and success was assured for Watt and his partner. Yet Watt was not satisfied with the engine as it was then. All his life he continued to improve it, devising newer and better cylinders, pistons, rods, and boilers.

Unlike many inventors, James Watt lived to reap the benefits of his invention. He saw the steam engine, thanks largely to his condenser, put into use for textile manufacturing, for ore-stamping, for hoisting coal, and for

other industrial purposes where water power or animal power had been used before. So great, also, was the financial success of his invention that in 1800 he was able to retire with an ample fortune.

In private life James Watt was a kindly and pleasing companion. He had read widely in several different languages and was able to hold his own in whatever society he found himself. In the preface to "The Monastery" Sir Walter Scott speaks of meeting Mr. Watt, who was then in his eighty-fifth year, and says that "the alert, kind, benevolent old man had his attention alive to everyone's question, his information at everyone's command." But what evidently pleased the novelist still more was to find that Mr. Watt was "as shameless and obstinate a peruser of novels as if he had been a very milliner's apprentice of eighteen."

James Watt is buried in Westminster Abbey; for, as his monument reminds us, he

> enlarged the resources of his country,
> increased the power of man,
> and rose to an eminent place
> among the most illustrious followers of science,
> and the real benefactors of the world.

John Ericsson (1803–1889)

Every American schoolboy has read of the encounter between the *Monitor* and the *Merrimac* in Hampton Roads on March 9, 1862. The story is that the little craft scoffingly referred to as "a cheese box on a raft" appeared suddenly one day after the steel-clad *Merrimac* had worked such destruction among the wooden ships of the North

that the city of Washington stood in imminent danger of being cannonaded. After a three-hour battle between these two steel-clad vessels, the *Merrimac* withdrew, never to give battle again. The Northern navy was saved, McClellan could transport his troops without hindrance from the South, and the city of Washington need no longer fear destruction from hostile ships. Little wonder, then, that the rejoicing Congress acknowledged the skill and foresight displayed in the construction of the *Monitor*, and expressed the thanks of the nation to the ship's designer, John Ericsson.

The skill which produced the *Monitor*, however, was a natural outgrowth of the boyhood activities of John Ericsson. His childhood was spent in his native Sweden, where his father was superintendent of an iron mine and later foreman of a construction gang working upon the Göta Ship Canal. In both places John learned all he could through careful attention to the work going on and through constant drawing of designs. When only ten years old he made models of a sawmill and a windmill, both of which worked perfectly. He also made models of canal boats, which he towed at various speeds, noting the wave motions produced. Doubtless these experiments suggested to the boy the theories of resistance which he later developed as important contributions to naval architecture. From one of the many English engineers who were in Sweden at that time, building highways and canals, John learned English, chemistry, algebra, and geometry. As he was already proficient as a draftsman, he soon learned field drawing also.

The death of his father, when John was about seventeen, caused the boy to enter the Swedish army. There he was

soon recognized as an expert in everything connected with artillery. He turned his attention especially to the study of guns and explosives and gained a broad knowledge of military and naval practice.

In a few years, however, he tired of military life and turned to his old interest in mechanical inventions. Confident at last that he had devised a successful engine in which the power would be furnished by flame instead of steam, he carried it to England in 1826. There, however, the substitution of coal for wood as fuel made his engine appear worthless. Discouraged at this failure and having spent all his savings, he was glad to find employment with an English manufacturer named John Braithwaite.

From 1826 to 1839 Ericsson remained in London with Braithwaite, first as employee and then as partner. During these years his inventions were many and varied. The first steam fire engine and a locomotive which made thirty miles an hour were two of the best-known. It was his experiments with screw propellers, however, which most influenced his later life. In 1835 he built a steamboat and equipped it with a propeller. When tried out on the river Thames, the boat made ten miles an hour, which was remarkable speed for that time. Although not accepted by the English naval authorities for many years, this invention really marked the end of the days of sailing vessels. Four years later Ericsson's machinery and propeller were used on the first screw-driven steamship to cross the Atlantic Ocean.

The success of his steamship brought Ericsson in 1839 to America. His first commission here was for a small iron warship, the *Princeton*, which was equipped with a

screw propeller and with other devices for speed and safety similar to those found today on all warships. So immediate was its success that by 1843 there were fifty steamers fitted out with screw propellers. For the next ten or fifteen years Ericsson continued his experiments in warship construction. Only a few years before the beginning of the Civil War he designed for the French complete plans for a turret warship. So when war broke out between North and South, he was ready to come to the aid of the North with the plans for the *Monitor*, which was the first warship carrying its guns in a single turret and with its machinery below the water line and protected by armor plate.

Just as his screw propeller had doomed the sailing vessel, so his ironclad *Monitor* doomed the wooden ship for war purposes. In the years following the Civil War, Ericsson built many ships of the *Monitor* type, from year to year perfecting new devices which increased their strength or speed. Other countries too called on him for help. He planned coast defenses for his native land and built gunboats for Spain. But to America, his adopted country, he devoted most of his skill. As late as 1887 we find him advising the United States navy concerning types of warships. Other inventions, too, appeared, such as the hot-air engine and the solar engine, the latter type producing steam by utilizing the rays of the sun. Though the principles were sound, this device has not proved practicable. In fact, so numerous were Ericsson's activities that at the time of his death, in 1889, he was credited with a greater number of independent devices for use in power machinery than had ever been invented by any other man.

James B. Eads (1820–1887)

If ever a river played an important part in the life of a man, the Mississippi did in that of James Buchanan Eads. From the morning in his boyhood when he was shipwrecked on its banks to the day, over fifty years later, when his death left unfinished a new plan for making the river useful, this man's fate was linked inseparably with the great river. Through it came the opportunity for his three greatest achievements, and from it he learned lessons not taught by books or schools.

Although James B. Eads was born in Indiana, he lived at different times in both Ohio and Kentucky. Before he was fourteen he had made two memorable trips on river boats. On the first, when the nine-year-old boy was on his way with his family to Kentucky, he displayed more than the usual boyish interest in the mechanism of the ship, and after their arrival at their new home he spent many days making models of engines run by steam. The second trip was less pleasant, but equally important. A fire on the boat which was carrying the Eads family to a new home in St. Louis left them stranded on the river bank. It is an interesting coincidence that years later James Eads was the builder of a bridge which crossed the river close by this landing-place.

When he was nineteen the river again called to James Eads. He secured a position as clerk on a Mississippi River steamboat. Although his work had nothing to do with the running of the boat, his interest in the river caused him to study it most carefully until he came to know its peculiarities as few others knew them. It is therefore not surprising to find that before long he gave

up his clerkship to become a partner in the business of salvaging river boats wrecked through the constant shifting of the channel.

It was to the raising of such boats, with their machinery and freight, that James Eads turned his skill. He and his partners worked up and down the river for hundreds of miles, salvaging many boats which had lain for years on the river bottom. As the insurance companies granted very liberal payments for such work, the partners in a few years found themselves wealthy. But what was more important to the future of James Eads was the fact that he came to be recognized as an authority on everything pertaining to the currents of the Mississippi River.

As soon as the Civil War began, the importance of controlling the Mississippi River was realized. It was indeed the "key to the situation": it cut the Confederacy in halves, and controlled their supply of men and food from Texas and Arkansas. Therefore, soon after the fall of Fort Sumter, the government at Washington sent for James Eads to aid them in defending the Western rivers. Thus it happened that while John Ericsson's *Monitor* was winning its victory on the Atlantic waters, a fleet of ironclad gunboats built by James Eads was clearing the upper Mississippi of all hostile craft and thus maintaining the Union supremacy in Western waters.

The next important achievement of Eads was the construction of a bridge across the Mississippi at St. Louis. This city had grown to a community of one hundred thousand people. If, however, it was to maintain its leadership as a river port, a bridge was an absolute necessity. Much opposition to its construction was made by the owners of the ferries then in use and also by those who believed the

river too wide to be spanned successfully. In 1867, however, Congress passed the bill for the construction of a bridge with a central span of not less than five hundred feet. The company of which James Eads was chief engineer undertook its construction. Again his knowledge of the river served him well: knowing the depth of the current and the constant shifting of the bottom, he insisted on sinking the piers to bed-rock. Later developments proved the wisdom of this precaution, although at the time it met with great opposition as a needless expense. After seven years of labor the bridge was completed, and during its many years of service it has done much to further the growth and prosperity of St. Louis.

It is with a third great achievement that his name is now most widely associated, namely, with the building of the Mississippi jetties. Below New Orleans the Mississippi flowed very sluggishly, and, broadening out into several mouths, wandered for miles over marshland before reaching the Gulf of Mexico. Across the openings, or mouths, sandbars had formed which cut off all navigation. For years government engineers had struggled to get rid of these bars, but none had been permanently successful. Eads, again calling on his knowledge of the river, proposed to make it scour out its own channel. He had learned that the amount of sediment which a river can carry along depends on the swiftness of its current, which, in turn, is determined by the slope, width, and depth of the river. Basing all his plans on these simple facts, he proposed to narrow the river at its mouth until he had increased the velocity sufficiently to force out into the deep waters of the Gulf the sediment which had formed the obstruction. Again his plans met with opposition; but again he proved

his point. With mattresses made from the willows growing along the banks he built artificial walls, or jetties. Upon these foundations he then erected stone or concrete walls. At the end of four years the river had actually deepened its own channel over twenty feet, just as Eads had intended it should, and the obstructing bars were gone forever.

The far-reaching effects of this work can hardly be estimated. Not only did New Orleans grow rapidly in importance as a port, but every farm and factory throughout the entire Mississippi Valley took on new value through the great impetus thus given to commerce. Had Eads lived long enough to continue this work by installing his system of river control, navigation would have been improved, and some influence would have been exerted to reduce the damage done by the disastrous floods which frequently sweep down the Mississippi Valley.

John A. Roebling (1806–1869) and Washington A. Roebling (1837–1926)

In the beautiful Cadwalader Park of Trenton stands a splendid stone monument topped by a bronze statue. On two faces of the stone pedestal are bronze panels bearing in relief reproductions of the Niagara Suspension Bridge and of Brooklyn Bridge. A third face bears an inscription, a part of which reads: "To John A. Roebling, civil engineer, designer and builder of many suspension bridges." Trenton contains also a still greater monument to its adopted son in the Roebling steel-rope works, which are continued today under the direction of Roebling's sons.

This builder of bridges came to America from his native

Germany, where he had received a degree as a civil engineer from the Royal Polytechnic School at Berlin. Even in his college days suspension-bridge building had interested him, and he chose this subject for his graduation thesis. In America he settled on a farm near Pittsburgh, which was then almost frontier land. The need of skilled men to direct the opening of canals and riverways, however, soon drew him from his farm to state employment as an engineer.

It was in this work that he defied tradition and took the step which determined much of his future success. That is, he first applied wire to the support of weights for which others had used stone piers or arches. When he announced his intention of trying this out on an aqueduct across the Allegheny River, other engineers ridiculed the idea. But he proved that it could be done, and followed this first success by several others on the Delaware-and-Hudson canal system.

Each success made greater the demand for Roebling's steel rope, for the making of which he had established a factory in Pittsburgh; and in 1848 he decided to build larger works in Trenton. The following year came the discovery of gold in California, which, of course, gave a great impetus to the western extension of the railways. Almost at once there was a conflict between railroad and steamboat interests. Rivers had to be spanned by bridges before railways could cross them; but stone piers and arches obstructed the passage of steamboats. The one man of the time to solve the difficulty was the pioneer wire-rope manufacturer. By force of argument and mathematical demonstrations, he won over the opposition to his design for a suspension bridge across Niagara. Five years later,

in 1855, a span over eight hundred feet long, carried by four wire cables ten inches in diameter, supported the first railroad train to cross a suspension bridge.

Other suspension bridges were built by Roebling at Pittsburgh and at Cincinnati, and while constructing them he was planning a still greater achievement. This was the building of a suspension bridge with a span of sixteen hundred feet to connect the cities of New York and Brooklyn. The greatest feature in the project was the placing of the cables high enough above the river to enable ships with high masts to pass underneath. The stupendous character of this undertaking delayed its beginning for nearly ten years. Then, unfortunately, it was too late for the designer himself to see the completion of this crowning achievement of his career. An accident at the very beginning of the work caused the death of Roebling in 1869.

Happily, however, a son, Washington A. Roebling, who had inherited much of his father's skill, had been growing up in close contact with his parent's work. He too was trained as a civil engineer and had assisted his father in the construction of the first suspension bridge over the Allegheny River. The Civil War interrupted his work for a time; but after taking part in several engagements, he resigned his commission (with the rank of colonel) in time to join his father in the making of the Cincinnati Bridge.

In the meantime John Roebling had been preparing the designs for the Brooklyn Bridge. When the other work was finished, he sent his son to Europe to study methods of foundation work and the manufacture of special steel for cables.

On his return to America, Washington Roebling took up his residence at Columbia Heights, Brooklyn, where

for the next fourteen years he was in constant sight of his work. In fact, his men often humorously complained that Colonel Roebling "took the bridge to bed with him every night."

His father's death before work was really begun on Brooklyn Bridge left Washington Roebling the threefold task of settling the affairs of his father's estate, conducting the wire-rope business in Trenton, and directing the construction of what at that time was the largest bridge ever built. The measure of his success is marked by the great bridge itself, still proudly serving its purpose.

The task, however, was too great for Colonel Roebling's physical strength. One afternoon he was brought out of the New York caisson nearly insensible. All night his life was despaired of, but he rallied and was back at work in a few days. Yet he never regained his former vigor, and soon he was too weak to go down to the bridge any more. He spent a whole winter writing out in detail the plans for the bridge lest he himself might die before it was finished. Then for nearly ten years he directed the work from the bed, where he lay by a window overlooking the bridge. In 1883 this devotion and determination were rewarded: the great Brooklyn Bridge was opened to traffic and declared one of the finest pieces of construction in the world.

George Westinghouse (1846–1914)

"If I understand you, young man, you propose to stop a railroad train with wind. That is impossible; I have no time to listen to such nonsense." These, we are told, were the impatient words of Commodore Vanderbilt,

owner and operator of several railroad lines. They were spoken one day not long after the close of the Civil War to a young man who had appeared before him with the design for an air brake to be used on railroad trains. In spite of the railroad magnate's unfavorable opinion, however, a few years later this same "impossible" device was in use on all the trains being operated by Commodore Vanderbilt, and the name of George Westinghouse had come into prominence as its inventor.

Even in the days when as a boy he worked in his father's factory at Schenectady, New York, George Westinghouse showed great interest in machinery and considerable inventive genius. After serving as an engineer in the United States navy during the Civil War and then spending two years at Union College, young Westinghouse returned to his father's shop, and very soon worked out and patented several minor mechanical devices.

In 1866 an accident occurred which had important results both for this young man and for the development of transportation facilities. On the railroad between Schenectady and Troy two trains crashed in a disastrous head-on collision. Investigation showed that the accident might have been averted had the trains been equipped with powerful and quick-acting brakes. George Westinghouse pondered deeply over this need and made many experiments. Three years later, in 1869, he took out a patent on his first air brake, and a train equipped with the device started out from the Union Station in Pittsburgh.

Although a great step in advance, this brake soon showed its weaknesses. It was a direct-action brake, in which the air was forced from the reservoir through a long pipe to the cylinders in the different cars. In a long train

this meant much loss of time in bringing the train to a stop. More serious still, in case of an accident in which any of the cars were uncoupled, the brakes ceased to work.

Westinghouse, therefore, continued his experiments, taking out over twenty additional patents on the air brake within the next two or three years. Finally, in 1872, he produced the automatic air brake. Whereas in the earlier type increased pressure applied the brake, in this later type decreased pressure applied it. So a high rate of speed could be kept up almost to the moment of stopping and yet a smooth and safe stop be made. Better still, if a train was torn in two, the brakes now worked automatically to stop the uncoupled cars. Thus one great danger was removed from railroad travel.

From brakes to signals was a natural step. Stand today in the yard of any great railroad center and watch the numberless trains roll in and out, each one choosing unerringly its own track and switch, and passing swiftly on without interference from the others. The speed and safety which characterize this miracle of modern railroading are due to the faultless working of the automatic block signals devised by George Westinghouse.

But the work Westinghouse did for the advancement of speed and safety in transportation was only the first of two fundamental contributions to civilization. In the later years of his life he turned his energies to developing the use of the alternating current in the transmission of electrical power. In this field Westinghouse was not so much himself the inventor as the great stimulating force to other inventors. When he first became interested in electricity as a source of power, the value of alternating current was just beginning to receive consideration; today

we are told that 95 per cent of all electric energy is transmitted by alternating current. Westinghouse was the first to see the big possibilities here, and by his organization of great companies he roused and encouraged the inventive genius of the younger men. Today one has only to turn to the pages of the daily newspapers or the current magazines to see advertised innumerable electrical devices which his companies have produced.

Years ago Macaulay said that "of all inventions, the alphabet and the printing-press excepted, those inventions which abridge distance have done the most for the civilization of our species. Every improvement of the means of locomotion benefits mankind morally and intellectually as well as materially." Judged by this standard, then, it does not seem too much to prophesy that when future historians look back upon this age of power, they will record among the names of those who have made the largest contributions to our civilization that of George Westinghouse.

Samuel Rea (1855–)

Undoubtedly the greatest accomplishment in railroad engineering of recent years is the linking of Manhattan Island with the mainland by means of the Hell Gate Bridge, the Hudson River tunnels, and the great Pennsylvania Station in the heart of New York City. Of course, thousands of men, unskilled laborers as well as trained engineers, contributed to the success of this undertaking; but the one man who stands out as master builder and commanding officer of the entire undertaking is Samuel Rea, for fifty years a worker for and a participator in the success of the Pennsylvania Railroad.

Dr. Rea began his long connection with this road in 1871, when he was only sixteen years of age. From his first work as chainman and rodman, he advanced rapidly to positions of greater and greater responsibility, becoming an assistant engineer before he was twenty-one.

One of the earliest constructions to which he was assigned was the "Point Bridge" at Pittsburgh. This chain suspension bridge, which was under construction during the Centennial year, 1876, was an object of great interest to the many European engineers visiting America that year. As one of the younger engineers, it was part of Samuel Rea's duty to show and explain the work to these visitors. Fifty years later, in 1926, this bridge was still in good structural condition, but the great demands of modern traffic made it advisable to replace it by a larger structure.

Even fifty years ago it was evident to the officers of the Pennsylvania road that New York City was the logical terminus for their road and that it should be reached on their own rails. From their point of view the ferries then in use were regarded merely as a temporary measure.

There were, of course, two methods of direct entrance to New York by rail: a tunnel under the river and a bridge over it. As early as 1874 an attempt at tunneling the Hudson was made, but it proved unsuccessful because of the objection to using steam locomotives. Hence it seemed for a time as if a high-level bridge would be the better method of entering the city. Plans for such a bridge were drawn, and a charter was secured. The inability of other railroads to coöperate in the undertaking, however, forced the Pennsylvania to abandon the project.

Yet all this time there were some officials of the Pennsylvania Railroad who favored the tunnel rather than the

bridge. Samuel Rea was one of these. For years he studied the project as it had been worked out in other places. In 1887 and again in 1892 he visited London and made an exhaustive survey of the underground systems there. His report and recommendations based on this study did much to persuade his company that a tunnel into New York City was feasible.

At length, in 1903, the great undertaking was begun. Samuel Rea was placed in charge of the threefold work of construction: the Hudson River tunnels, the Pennsylvania Station, and the Hell Gate Bridge. In 1910 the first trains ran out of the great terminal station through the new tunnels, and the opening of the Hell Gate Bridge in 1917 completed the project. Thus the Pennsylvania Railroad had effected an all-rail direct line between New England and the Southern and Western states.

During these years Rea had been advanced from one position to another, until in 1912 he was elected president of the road he had served so long. This position he held until his retirement in 1925. Colleges and societies also took note of his achievements and conferred degrees upon him. He became a Doctor of Laws of Lafayette and a Doctor of Science of Princeton. In 1926 the Franklin Institute made him an honorary member and awarded him the Franklin medal, "the highest honor in the gift of the Institute." In conferring this medal Dr. Walton Clark, who introduced Dr. Rea, spoke of their pleasure that "the first Pennsylvanian to receive this medal has earned the title to it in a field in which the application of science to industry — the immediate application of useful discovery and invention to the betterment of man's condition — is an outstanding feature."

In his speech of acceptance Dr. Rea showed that although he had retired from active participation in the work of the road, he still followed its movements with interest and looked forward to still greater developments, stating his belief that the rapid growth of passenger and motor traffic would soon make necessary more bridges as well as tunnels across the Hudson and East rivers.

George W. Goethals (1858–1928)

Many of the early explorers, including Columbus, sought a short route to the Indies; and in doing so they visited the shores of Panama, where now is the eastern entrance of the Panama Canal. That little strip of land which connected the two Americas was so tantalizingly narrow that even the Spanish *conquistadores* talked of the possibility of a canal across the Isthmus of Panama. With the discovery of gold in California in 1848 the demand for some shorter route thither became so insistent that a railroad was built between Colon and Panama. Yet this was regarded by everyone as merely a temporary measure, — a ship canal was the real need. So it was natural enough that Count Ferdinand de Lesseps, the successful builder of the Suez Canal, should undertake a similar project in America. The story of his disastrous struggle against dishonesty and disease is well known. After the loss of three hundred million dollars and the lives of hundreds of his workers, De Lesseps was forced to abandon the struggle.

The entrance of the United States upon the scene as a canal-builder came in 1902, when Congress authorized the purchase of the Colon-to-Panama railroad and the French canal rights. An Isthmian Canal Commission had been

appointed, and work was begun under Chief Engineer John F. Wallace, who was succeeded the next year by Chief Engineer John F. Stevens. Colonel, afterwards General, Gorgas was the chief sanitary officer and as such deserves much credit for the conquest of malaria, yellow fever, and typhoid. This victory made the completion of the Canal possible, as disease was the principal cause of the failure of the French enterprise. General Gorgas was afterwards appointed Surgeon-General of the United States army.

In 1907 Lieutenant-Colonel Goethals, of the United States army, was appointed chief engineer in charge of the construction of the Panama Canal. President Roosevelt often said that he never hesitated about this appointment, — that all indications pointed to Colonel Goethals as the man for the place. Perhaps the comment of a superior officer during the early army days of Colonel Goethals may partly explain this. He said: "Whatever I gave him to do I immediately dismissed from my mind. I knew it would be done right." The best evidence of the truth of this opinion is found today in the great Canal through which the ships of the world pass from the Atlantic to the Pacific, the modern engineering achievement that outranks any of the seven wonders of the ancient world.

It is an interesting fact to all Americans that this builder of our Canal bears the name of another great American, the builder of our nation. George Washington Goethals, although of Dutch parentage, was born in the United States. He grew up in his birthplace, Brooklyn, New York; and from the time he was eleven years old he worked at various jobs in order to contribute toward the family income. After putting himself through the College of the

City of New York, young Goethals found his health was not sufficiently good to make advisable his following the surgeon's profession, which was his first choice. Therefore he secured admission to the United States Military Academy at West Point. The regular routine of military discipline soon restored him to excellent physical condition, and he applied himself with interest to his new life. His graduation in 1880 was marked by a threefold distinction rarely attained by a cadet: in scholarship he stood second in a class of fifty-four, in recognition of his power as a leader he was chosen by the faculty as one of the four cadet captains, and by the vote of his classmates he was the unanimous choice for class president.

The high scholarship maintained by George Goethals at the Academy secured for him appointment to the Engineers' Corps, an honor given to but two of his class. During the next ten years he continued his studies in higher mathematics and engineering problems, giving practical demonstration of his ability in such constructions as the Muscle Shoals Canal on the Tennessee River. As an instructor in civil and military engineering at the Academy he inspired his pupils with his own enthusiasm for the work and thus won marked success as a teacher. During the Spanish War he did much useful work as Chief of Engineers in Porto Rico, and by 1903 he had attained the rank of major and was engaged in the construction of harbor fortifications at Newport, Rhode Island. In all these assignments he displayed the same qualities of accurate knowledge, good judgment, and ability to direct men. So, as we have seen, his superior officers turned naturally to him when there was need of a man to take charge of the building of the great Panama Canal.

In this undertaking Colonel Goethals found that one of the most effective ways of handling the men was through good-natured rivalry. First of all, he divided the entire work into three sections, which he called the Atlantic, Central, and Pacific divisions. Each of these he placed under a skillful superintendent, and then treated the workers as three teams competing in a great game. Every week the results of the work of each division were printed in the *Canal Record*, of which every worker had a copy. There Steam Shovel Gang No. 37 of the Atlantic division learned, perhaps, that the rival gang in the Pacific division had gained two points over them; no other incentive was needed to drive No. 37 to beat that record the next week. The weekly records were followed as closely as baseball scores, and thus, by playing one team against the other, from each was drawn the maximum of work.

It was the firm belief of Colonel Goethals that no piece of public work could be satisfactorily done through committees, boards, or commissions. "All boards," he once said, "are long, narrow, and wooden." He insisted that sole responsibility should be given to one man. Of course, it was natural that a man with such ideas should be called an autocrat. If an autocrat is one who demands from every man his best work and insists that to every man be given full credit for the work accomplished, then perhaps he was. His orders were clear and emphatic, and disregard of them meant instant dismissal; on the other hand, no leader ever took greater precautions to guard the health and safety of his men or listened more patiently to their grievances. When, after the completion of the Canal, he was made Governor of the Canal Zone, he

administered with justice and ability a civil population made up of widely differing elements.

Colonel Goethals has always been a doer rather than a talker. Yet, like most men of few words, he can make those few most effective. The following quotation from an address made by him to a graduating class at West Point not only expresses his own ideals for his profession but serves as excellent advice to the young man about to start out on an engineering career:

> To accomplish successfully any task it is necessary not only that you should give it the best that is in you, but that you should obtain for it the best there is in those who are under your guidance. To do this you must have confidence in the undertaking and confidence in your ability to accomplish it, in order to inspire the same feeling in them. You must have not only accurate knowledge of their capabilities, but a just appreciation and a full recognition of their needs and rights as fellow men. In other words, be consistent, just, and fair with them in all dealings, treating them as fellow members in the great Brotherhood of Humanity.

Charles P. Steinmetz (1865–1923)

One day in 1892 a paper was read before the American Institute of Electrical Engineers by a small man, — in fact, a dwarf, — physically deformed, whose command of English was very imperfect. Yet after the first few sentences all this was forgotten by the audience in their amazement at the mathematical deductions he had made and the new electrical law he had discovered. Scientists all over the world read the printed reports of his address, and newspapers and magazines made known to all the name of Charles Proteus Steinmetz.

This mathematical genius was a native of Germany, but was exiled in early youth because of his pronounced socialistic views. He continued his education in Switzerland, where he met an American student who advised him to come to America. Accordingly, he arrived in New York in 1889, and soon secured work in Yonkers, with the manufacturer and inventor Rudolf Eickemeyer.

The association of these two men did much to determine the future of Charles Steinmetz. Eickemeyer, who was himself one of the earliest experimenters with electricity, quickly recognized the ability of his young employee. He set him to work first on designs for motors to be used in street cars. When these motors were tested the next summer in Brooklyn, the two men were interested observers and came to know each other better. As a result, a few months later Eickemeyer set up in his factory a crude experimental laboratory and placed it in charge of Steinmetz.

To this laboratory came the design for one of the first alternating-current motors. From his study of this, Steinmetz worked out, by means of involved mathematical processes, the so-called "law of hysteresis," or the loss of energy caused by changes in magnetism. It was the announcement of this law that made so profound an impression on the gathering of electrical engineers in 1892.

Honors now came rapidly to Steinmetz. He was elected president of the American Institute of Electrical Engineers; he became head of the department of electrical engineering at Union College, Schenectady, New York; he was induced to prepare a series of textbooks setting forth his discoveries and experiments; and later he joined

the engineering staff of the General Electric Company at Schenectady. That he was the acknowledged leader in the field of electrical research was shown when, in 1902, Dr. Charles W. Eliot conferred on him the degree of Master of Arts of Harvard University with these words: "I confer this degree upon you as the foremost electrical engineer in the United States, and therefore the world."

The investigations of Dr. Steinmetz covered a wide field, but he himself named three as his most valuable achievements. These were his discovery of the law of hysteresis, his development of a practical method of making calculations for the design of alternating-current machinery, and his study and theories concerning electrical transients. During the last years of his life he gave much time to the third of these; but many of his experiments were incomplete at the time of his death. He had, however, roused much popular interest by his study of the phenomena of lightning and by the production in his laboratory of bolts of lightning which developed a million horse power in a single crash.

This remarkable achievement caused many people to refer to the producer of the thunderbolts as the "modern Jove," but the name was never pleasing to Dr. Steinmetz. He had no desire to appear to dominate or control. Throughout his life he was the kindliest of men, social in his nature and simple in his tastes. Much more to his liking was the earlier nickname of "Proteus," given him during his student days in Germany. According to mythology, Proteus was a sea god who assumed many shapes; so the young student interested in many different subjects had seemed a "Proteus" to his classmates. After coming to America the old name of student days was

adopted by him as part of his official signature. To those who knew him best it seemed very appropriate. They saw the scientist in his laboratory, working out involved mechanical problems; and the instructor in the classroom, explaining his discoveries to others. But they saw also, in his leisure hours, the man who loved plants, as he bent over some rare specimen in his greenhouse; the man who loved the out-of-doors, as he tramped through the woods or paddled up and down the river in his canoe; and the man who loved, most of all, human companionship, as he sat around his own fireside with his adopted family and friends. Seeing how easily he could tell fairy stories to the children or discuss sports with their older brothers, they knew that the man who was known to the world as the "electrical wizard" was indeed a man of many interests, a very Proteus.

HERBERT C. HOOVER (1874–)

"Hooverize: to save; to economize, be sparing in the use of, as food." So reads an addendum to Webster's International Dictionary; but behind this bald statement there lies the life story not merely of one man but of a whole continent. Those who were most intimately connected with the making of this story say that to them the word had a better meaning. It stood for "efficiency with a heart in it," the controlling influence of Herbert Clark Hoover.

In a small Quaker colony in Iowa, Herbert Hoover was born on August 10, 1874. The death of both parents within the next ten years left the three Hoover children to the care of various kindly Quaker relatives. As a result

Herbert spent his boyhood in many different homes in the Western and Middle Western states. When the time approached for him to consider the selection of his life work, a chance visit from an old friend of his father's had much influence on the boy's choice. This man, a mine-owner and probably a mining engineer, gave such interesting accounts of scientific mining methods that the boy announced his intention of making mining his profession. Fortunately, a new university which emphasized scientific training was just opening; and thus it happened that Herbert Hoover was enrolled in the first class to enter Stanford University, at Palo Alto, California.

Herbert Hoover's life at the university, while not remarkable in any way, did show the development of certain characteristics which distinguished his later career. One was his marked gift for organization, which at college served the double purpose of earning the money to meet his college expenses and of putting the financial affairs of his class on a secure basis. Another was his thoroughness. In addition to his classroom work in geology, in which he always excelled, he spent two summers with the United States Geological Survey in the (California) Sierra Nevada Mountains. The training received there proved an important factor in his subsequent advancement.

After graduation in 1895 Hoover worked for several months as a common miner. Then he sought employment with Louis Janin, the most prominent mining engineer on the Pacific coast. The thoroughness of his field work and the accuracy of his reports soon made him a valuable member of the Janin organization.

In 1898, when Hoover was twenty-three, a great mining boom came to West Australia. A British firm asked

Mr. Janin to send them an experienced engineer to introduce American methods in the new fields in Australia. Mr. Janin immediately sent Hoover, who spent the next eighteen months in Australia as engineer for the group. Later he acted as general manager of an important mine, during which time he was tendered the position of Chief Engineer of the newly created Department of Mines in China.

Between the last two appointments Hoover spent some months in the United States on important mining engineering jobs and the day before leaving for China he was married to Miss Lou Henry, who had been his former classmate at Stanford University.

The young couple found much of interest in their travels, for Hoover spent the next nine months in exploration of the interior of China. But this pleasant period was brought to an end by the growing hostility to foreigners, which flamed out in the Boxer Rebellion. Hoover and his engineering staff came into the foreign settlement at Tientsin for safety in the storm, and being the only engineers in the settlement they were promptly enlisted by the military authorities to take charge of building barricades and defenses, providing water and supplies. In addition they undertook to feed and protect some thousands of pro-foreign Chinese who had also flocked to the settlement for protection. For three weeks the settlement was under continuous bombardment, at the end of which time reinforcements came from the outside and Hoover was again free to attend to his own private affairs. But the Chinese government had disappeared and his job was ended.

He was then engaged as chief engineer to a large mining and transportation company, and after a visit of some

months in the United States, he again served in China for a year, but bitter quarrels amongst the owners, and the failure of some of the foreign elements to treat the Chinese fairly, caused him to resign and return home to California. He then opened a practice as international consulting engineer and administrator of industrial concerns scattered over the entire world. With the coming of his two sons there was the necessity of more settled existence and he established a home at Stanford in 1910, and worked outward from the United States entirely, going abroad some months of each year in direction of a group of engineers with whom he surrounded himself in various offices in San Francisco, New York, London, Petrograd, Mandalay, and elsewhere.

In 1914 he was requested by the directors of the Panama-Pacific Exposition at San Francisco to go to Europe and enlist the support of European governments in the Exposition, and thus he was in Europe at the outbreak of the World War. Hundreds of Americans found themselves, because of the moratorium, unable to get money. Again Hoover came to the relief of his countrymen. Hastily gathering a few friends to aid him, he advanced money on checks drawn by hundreds of unknown Americans on banks almost equally unknown to him, and secured passage on already overcrowded ships for many who had themselves been unable to secure accommodations.

It is little wonder, then, that when the magnitude of the struggle began to be realized, Herbert Hoover was again appealed to for help, first in relieving the civilian population of invaded Belgium, then in a wider field. In undertaking the work, Hoover put aside his own business interests, not only "for the duration of the war," as the

soldier did, but for the days following the armistice, when his work was even more necessary.

No brief biography can more than mention the work done by Hoover on the Commission for Belgian Relief, as Food Administrator for the United States, and as chief of the American Relief Administration. Volumes have already been, and more will be, written on this work. Hoover and his associates saved the lives of whole nations; they fought not only starvation but anarchy; they made possible the rehabilitation of the war-torn countries.

Then Hoover came home to be an American private citizen again. He would accept no decorations and no special honors. But the people of the nations he saved are not likely soon to forget him. At a special ceremony after the armistice, the king of the Belgians solemnly pronounced him "Citizen of the Belgian Nation and Friend of the Belgian People," and many citizens in countries other than Belgium still hold in grateful memory this man who has proved himself a citizen of the world and a friend to all its people.

JOHN HAYS HAMMOND (1855-)

The splendor of King Solomon's court has come to be a basis for all comparison of luxury. Second only to "Solomon in all his glory" is the Queen of Sheba, who brought to him her gifts of gold; and we read in the Old Testament story of hundreds of slaves bringing this gold from mines in the "land of Ophir." But where was this land of Ophir? When H. Rider Haggard located these mines in southern Africa, the reading world considered it merely a part of the novelist's fiction. But can we refuse

to accept the statement of a mining engineer of unquestioned authority? "No possible question exists that it was in what is now called Southern Rhodesia that King Solomon and the Queen of Sheba got their quantities of gold." In this sentence we have the definite assertion of John Hays Hammond.

The end of the last century saw the opening up of the great resources of the continent of Africa. In this development no name is better known than that of Cecil Rhodes, the man whose wealth today makes possible the Rhodes scholarships; and this wealth was taken largely from the gold mines of South Africa. Of course such an undertaking required the aid of skilled engineers, of whom the best-known was John Hays Hammond.

Born in San Francisco in 1855, Hammond was educated in the West until he entered the Sheffield Scientific School, at Yale University. He followed this training by attendance at the Royal School of Mines at Freiberg, Germany, where he decided to make gold-mining his specialty. Then, returning to America, he gained much experience in the gold fields of the Pacific coast and of Mexico.

Hammond's first work in Africa was for the rival of Cecil Rhodes, Barney Barnato, the diamond king. The policies of the engineer and his employer not being in agreement, however, Hammond left Barnato, and was immediately employed by Cecil Rhodes to take charge of and develop all his mining properties. At that time Hammond was probably the highest-salaried mining engineer in the world.

In 1894 Hammond and Cecil Rhodes made the journey northward from the Transvaal to the mines in Southern Rhodesia. There, for a distance of about a thousand miles,

they found stretches from ten to twenty miles in length that had been excavated by the ancients. Examination convinced them that the mines had been abandoned suddenly, but not because they were exhausted. Although it was estimated that at least a hundred million dollars' worth of gold had already been taken out, there was plenty left. Upon the advice of Hammond, Rhodes decided to bring in modern machinery and explosives, reopen the mines, and go on from where King Solomon and the Queen of Sheba had left off. All this was done, and again we have Hammond's statement that today "the mines of the Scriptural Ophir are yielding something like twenty million dollars' worth of gold a year."

Another member of the party who visited the mines in Rhodesia was Dr. Jameson of Kimberley. This is the man who in 1895 led a raiding party into the Transvaal. He was obliged to surrender to the Boers, and escaped death at their hands only by being handed over to England for punishment. As a result of this raid many of Jameson's friends and associates were suspected by President Krüger. Among them was John Hays Hammond, who was arrested and condemned to death. After long negotiation, however, a ransom of two hundred and fifty thousand dollars was accepted by the Boers.

Long experience in mining operations in many countries (the last of which was Russia just before the World War) has convinced Hammond that certain characteristics are necessary for any man who contemplates mining engineering as a profession. These he sums up as follows:

> He must be physically robust. He must have the restless temperament of the explorer, . . . [who is] adaptable to strange conditions. He must be a leader of men. . . . He must have sure,

instantaneous judgment; . . . endless courage; an indifference to criticism inspired by animus, and to erroneous public opinion. Most important of all, he must be honorable, meticulously scrupulous in the handling of property intrusted to his care.

Charles M. Schwab (1862–)

From stage-driver to steel magnate; from stake-driver to master builder,— that is the story of a boy born in the little town of Williamsburg, Pennsylvania, in 1862. Later his parents moved to Loretto, a village at one of the highest points in the Allegheny Mountains. There Charles M. Schwab went to school, and there he earned his first money, driving the village stage. In later years, after he had acquired wealth, Schwab returned there to build himself a house rivaling a castle in splendor and surrounded by lawns and gardens of great beauty.

As a young man he went to Pittsburgh and gained employment in one of the numerous firms controlled by Andrew Carnegie. Although his first job was the very humble one of driving stakes for the surveyors, his advancement was rapid. He became one of Carnegie's "lieutenants," and was, in turn, engineer, assistant manager, manager, and general superintendent. By 1901 he was president of the United States Steel Corporation, the largest producer of steel in America.

Then Schwab turned to shipbuilding; and when the World War broke out, his firm was the leading producer of heavy armor plate for battleships and of heavy guns.

The story of Schwab's war work is particularly striking. Before the United States entered the World War, his company supplied the Allies with huge quantities of

ammunition. It is well known that he held contracts, especially from Great Britain, for hundreds of millions of dollars, — contracts that Germany would gladly have paid much more to see canceled.

When the United States entered the World War, President Wilson asked Schwab to be Director-General of the United States Shipping Board. An enormous shipbuilding program was undertaken and, thanks to the ingenuity of Charles M. Schwab, successfully carried out. The task of directing thousands of workers, many of them entirely untrained, in the midst of the uncertainties of a war period was one requiring not only knowledge of shipbuilding but even greater knowledge of men. The loyalty of the hundred thousand workmen in the employ of the Bethlehem Steel Corporation, of which he is chairman, is a pronounced factor in its prosperity and in the success of its manager.

Schwab has always been one of the chief exponents of good human relations in industry. In one public address he said:

> Today the achievements of the engineer are among the wonders of the world. But I do not mean engineering in the mechanical sense alone. The people who labor are human beings, full of sentiments, hopes, and aspirations. Therefore, the fundamental problem of all industry is to relate the human elements so that the whole process will go forward without hitch or trouble.

He believes that only by such an adjustment between laborer and employer will the industrial world go forward to greater things.

INDEX

Aptitude, 15, 17
Architectural engineering, 76
Architecture, 75

City planning, 94
College, why students drop out of, 65

Eads, James B., 166
Engineering,
  a brief history of, 40
  administrative, 134
  aëronautical, 134
  æsthetic, cultural, and romantic in, 146
  architectural, 76
  as a life work, 11
  automotive, 134
  bridge, 93, 135
  ceramic, 135
  chemical, 58, 126
  civil, 43, 82
  the college course in, 60
  definitions of, 44, 45
  electrical, 56, 96
  electrochemical, 135
  functions, 23
  general, 134
  highway, 84
  hydraulic, 87
  industrial, 58, 120
  marine, 136
  mechanical, 53, 110
  metallurgical, 130
  mining, 59, 130
  municipal, 86
  naval, 137
  railway civil, 86
  railway electrical, 137
  railway mechanical, 138
  sanitary, 90
  structural, 93
Engineers, opinions of, 71
English, importance of, for engineers, 72
Ericsson, John, 162
Ethics, code of, 8

Factory management, 124

Geodesy, surveying and, 94
Goethals, George W., 178
Graduates, earnings of, 27

Hammond, John H., 189
Hoover, Herbert C., 185

Personal characteristics, 36
Personal qualifications, 24
Personnel and inspection, 124
Personnel forms, 37, 38
Positions occupied, types of, 28

Rea, Samuel, 175
Research, teaching and, 139
Roebling, John A., 169
Roebling, Washington A., 169

Schwab, Charles M., 192
Steinmetz, Charles P., 182
Surveying and geodesy, 94

Teaching and research, 139
Time study, 123

Vinci, Leonardo da, 157
Vocation, selection of a, 1
Vocational guidance, 35

Watt, James, 159
Westinghouse, George, 172